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AIRCRAFT ENGINE RELIABILITY ANALYSIS
USING
LOWER CONFIDENCE LIMIT ESTIMATE PROCEDURES

by

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The model is capable of supporting LCL decisions in support of the Component Improvement Program or a new weapon system procurement where reliability growth analysis is used as a decision support tool. This procedure also provides program managers and engineers with a method to perform LCL analysis and thereby reduce their dependence on contractor supplied reliability data..

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Aircraft Engine Reliability Analysis
using
Lower Confidence Limit Estimate Procedures

by

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ABSTRACT

In this thesis, a spreadsheet model was developed to compute the lower confidence limit (LCL) for the reliability of a complex weapon system using a personal computer. The LCL is an estimate of the lowest reliability a system is expected to have at a given point in time with a given level of confidence. The reliability model is based on a Weibull distribution for the system component failure times. The reliability LCL procedures has been extensively validated and determined to be quite accurate when the expected number of failures is at least 10.

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TABLE OF CONTENTS

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I. INTRODUCTION

The U.S. Navy recognized years ago the need for data analysis capabilities to support growth in sophisticated and complex weapon systems. The Naval Aviation Logistics Data Analysis (NALDA) database was established to provide this service and to make its resources available to managers, engineers, analysts and logisticians. NALDA is an Integrated Logistic Support data collection facility incorporating numerous database management systems designed to maintain historical records of naval aviation weapon systems and performing routine analysis of those records.

One of the tasks that NALDA was designed to perform is basic reliability analysis on simple systems or components and estimates of that reliability. Reliability is the probability that a system or component will perform at a desired level for a given period of time under specified operating conditions [Coombs and Iverson, p 19.2, 1988]. Unfortunately, some special database sorts and summaries are required if NALDA is used to perform lower confidence limit (LCL) reliability analysis for complex systems. Lower confidence limit reliability analysis is important because it provides a lower bound for the system reliability with a prescribed level of confidence.

The lower confidence limit reliability analysis procedure used in this thesis provides an estimate of the reliability of a complex system when only a portion of the historical data is available for analysis. This procedure can be very useful during the development phase and the re-engineering phase of a weapon system. The reason to perform LCL analysis is best expressed in the following quote:

> Lower confidence estimate procedures for system reliability are needed during the development phase of systems to provide indications of a contractor's ability to meet a stated system reliability goal as development progresses and the results of test programs become available. These procedures are also needed to assess the reliability of systems that have been operating in the field for some time and have accumulated histories of failure data and unique configuration of modified or repaired components. [Yee, p 1]

NALDA's inability to perform lower confidence limit procedures for system reliability of complex systems directly, motivated the author to discover a more effective method to utilize the NALDA database to perform better analysis of available aircraft engine data.

A. PURPOSE

The primary purpose of this thesis is to develop procedures to utilize LOTUS 1-2-3 with current reliability models to determine lower confidence limits (LCL) on the reliability of the F404-GE-400 (F404) engine in the F/A-18 aircraft. The author decision to use the F404 engine is based on his background and knowledge of the engine and the fact

that the F404 is considered the baseline engine for all new aircraft engine generations.

The secondary propose of this thesis is to provide the decision makers in aircraft/engine programs with a tool to calculate LCL for the system reliability of a complex weapon system using a personal computer. This procedure will reduce the degree decision makers rely on other Navy agencies or Commercial Contractor support.

B. LOWER CONFIDENCE LIMIT PROCEDURE BACKGROUND

The confidence interval procedures for the reliability of complex system utilized in this thesis were developed by Woods and Yee [1991]. The procedures were evaluated using 1,000 computer simulations for a series system composed of components that have either all exponential failures modes, all Weibull failure modes, or a mixture of exponential and Weibull failure modes. The results of the validation tests were compared to the actual reliability and determined to be quite accurate for large sample sizes when the expected number of failures are at least 9.6. [Yee, p 25, 1991]

These LCL procedures developed by Woods and Yee can be used for any complex quasi-coherent system whose reliability does not decrease when the reliability of any one of the subassemblies or components is increased.

The F404 engine is a complex quasi-coherent system consisting of six (6) module and numerous accessaries. The

failure times of the six (6) modules are assumed to have a Weibull distribution with parameters (β & λ) considered to be unknown. The exponential distribution is considered a special case of the Weibull distribution with its shape parameter, β, equal to one. The Weibull distribution is often used to model the lifetime probability distributions of rotating mechanical devices, because its failure rate function increases with operating time as is the case with mechanical devices.

Yee's procedure can be further extended to determine LCL on the reliability of any subassembly (e.g., module) of the F404 or composite of its accessories. All that is required in order to apply Yee's LCL procedures is a knowledge of the reliability block diagram of the system to be analyzed.

C. RELIABILITY BLOCK MODEL

A reliability block diagram provides a description of how the subassemblies of a weapon system are interrelated. They can be arranged in a series, parallel or a compounded series-parallel network. The reliability block diagram in this thesis is derived from the basic model developed by General Electric in 1978. The reliability model is a serial network that includes only the six basic modules of the engine. No other modification of the model developed by G.E. was required,

because the engine operates in a series network manner. An example of the reliability block model is as follows:

```
 ______      ______      ______      ______      ______      ______
|  FAN |    |  HPC |    | COM- |    |  HPT |    |  LPT |    |AFTER-|
|      |==> |      |==> |BUSTOR|==> |      |==> |      |==> |BURNER|
|MODULE|    |MODULE|    |MODULE|    |MODULE|    |MODULE|    |MODULE|
|______|    |______|    |______|    |______|    |______|    |______|
```

The reliability block model in this thesis assumes that each module fails independently of the others. It also assumes that each module can only be in one of two states, operational or failed. Simply stated, the interrelationship of a series network means if any one of the modules fails then the engine fails [Blanchard, p 33, 1992].

The thesis research conducted by Poernomo [1992] extended the reliability block models from exclusively series systems developed by Yee to compounded series-parallel systems. Poernomo also used a different method to estimate the shape parameter $\{\beta\}$ in the Weibull distribution. These procedures would be extremely useful in calculating LCL for reliability of a complex system with multiple built-in redundancies.

D. METHODOLOGIES

To obtain realistic lower confidence limits on engine reliability for projected operating hours up to 1000 hours, it was necessary to obtain useable life history data over the past ten years from the NALDA database on the major subassemblies (modules) of the F404.

Information on the failure times that have occurred on the first 200 serial numbers of each module and the total operating time on each of those modules was requested from NALDA. The NALDA data provided for this thesis consisted of historical records for 181 Fan Modules, 189 High Pressure Compressor Modules, 183 Combustor Modules, 194 High Pressure Turbine Modules, 170 Low Pressure Turbine Modules and 144 Afterburner Modules.

With this information, a hierarchial data structure was developed for use in computing the Weibull shape and scale parameters of the engine components and LCL of the system reliability. The data was screened under three increasingly restrictive criteria (cases) to determine the reliability of the F404. The criteria for the screening is as follows:

Case 1. The data will be processed first with no restrictions. Once a module failure has occurred, it is repaired and placed back in service. At this time, the module is considered new with zero accumulated hours to next failure and no internal wear. The elapsed time between subsequent failures counts as an independent failure and not related to the previous failure of that serial number.

Case 2. The data will be reprocessed and all second and subsequent failures occurring with less than 100 operating hours after repair will be removed. This eliminates any maintenance related failures from the analysis and provides a more accurate estimate of the system reliability LCL.

CASE 3. The data will be reprocessed a third time to eliminate all operating time after the first failure has occurred for each serial number. The resulting data should yield a more accurate estimate of the lower confidence limit for reliability to first failure of an F404 engine. This is because not all components in a module that wear internally are replaced during repair and the repaired module is not in a new condition, but it is somewhat like new (i.e., some wear exists internally).

Lower confidence limits of 80%, 85%, 90%, 95%, and 99% for engine reliability will be calculated and a comparative analysis conducted to determine if a significant difference exists between cases 1, 2, and 3. This should also provide an estimation of the quality of maintenance performed during the repair of the F404.

E. THESIS ORGANIZATION

This thesis is divided into six chapters: an introduction, two background chapters, LOTUS modeling chapter, data analysis chapter and a summary which includes conclusions and recommendations.

Chapter II includes a historical background of NALDA, a description of sample NALDA applications available for use, data collection programs and database management concepts. Chapter II also contains a description of how data is stored and structured, and samples of NALDA data printouts. NALDA

data accuracy and integrity is also discussed along with recommended improvements.

Chapter III provides a description of Yee's lower confidence limit model used in this thesis. A procedure to apply his model to LOTUS 1-2-3 to estimate the shape parameter and calculate lower confidence limits is developed and discussed.

Chapter IV discusses the procedures required to restructure the NALDA data into a LOTUS usable format. The procedures required to input data ranges into the spreadsheets to calculate the shape parameters for each module, and LCL of the system are provided.

Chapter V discusses the results of case one (1) through three (3) and an analysis is performed comparing the results.

Chapter VI summarizes the LCL for reliability procedures used in this thesis and provides conclusions and recommendations for their use within the U. S. Navy.

F. SUMMARY

Computing lower confidence limits for reliability of complex system is important to the Navy in order to determine if overall system reliability goals are being maintained. A validated reliability block model and accurate NALDA data is essential in order to perform a proper analysis.

II. NAVAL AVIATION LOGISTICS DATA ANALYSIS (NALDA)

A. HISTORICAL BACKGROUND

NALDA is an Integrated Logistics Support (ILS) data collection facility capable of providing improved logistics data analysis capability to any command involved in the analysis and management of logistics and engineering. This objective is achieved through a "state of the art" database management system (DBMS) tailored to support various logistic Management Information Systems (MIS), user data analysis programs, and interactive query requirements.

The DBMS system utilized for this purpose is the SYSTEM 2000 using the S2K query language. The Navy provides instruction to any military and civilian personnel in how to use the S2K query language to transmit instructions to the computer in order to retrieve data tailored to his/her unique requirements. [NALDA Users Manual, 1991]

B. NALDA APPLICATION AND DATA COLLECTION PROGRAMS

NALDA also provides its users with real-time interactive data retrieval capability for analysis purposes and required integrated application program computer support. These services could have a significant impact on decisions affecting logistic requirements and reliability engineering. Some of the major application programs are:

- AMPAS: Analytical Maintenance Program Analysis Support System is used to support reliability centered maintenance concepts.

- TDSA: Technical Directive Status Accounting System is used to manage the incorporation of Technical Directive in aircraft, engines, components, and Ground Support Equipment (GSE).

- MIR: Master Index of Repairable is used to accurately identify all repairable components including life-limited components and forecast their workload requirements to each operational field activity and repair site.

- ECOMTRAK: Engine Composite and Tracking is a program designed to project and track material and workload requirement for specific type-model-series engines and critical engine components. This information is vital to the support of the Component Improvement Program.

- ECP-TRAK: Engineering Change Proposal, Tracking and Evaluation is used to monitor and evaluate all ECPs from initial action by the NAVAIR Change Control Board to ultimate disposition, including their installation as Technical Directives.

The major data collection systems in the Navy that provide data to NALDA are stand alone programs providing separate

services to various commands. A portion of the different data collection systems available are:

- Maintenance Data System (MDS): It is a historical record of the scheduled and unscheduled maintenance performed on aircraft, engines, weapon systems and GSE at the Organizational (Squadron) and Intermediate (Ship/Station) level. These maintenance actions are documented via Visual Information Display System/Maintenance Action Form (VIDS/MAF) and Support Action Form (SAF).
- Aircraft Engine Management System (AEMS): It is the most accurate historical record (life) of each engine in the naval inventory. Maintenance actions are reported through Engine Transaction Reports (ETRs) submitted by the Organizational, Intermediate, Depot, and Supply activities in the U.S. Navy whenever an engine is removed, replaced, repaired and shipped. All data pertaining to incorporation of Engineering Change Proposals, modifications and everyday maintenance can be cross referenced here to establish an accurate time when performed.
- Depot Maintenance Data System (DMDS): It provides maintenance and material data generated for equipment overhauled and/or modified by the Naval Aviation Depots

(NADEPs), and other Department of Defense (DoD) and contractor depots.

- Naval Aviation Logistics Command Management Information System (NALCOMIS): It provides MDS data and information concerning the tracking of repairable components through the Organization/Intermediate Maintenance Activities (OMA/IMA) and Supply Support Centers (SSCs).

NALDA is capable of tracking all systems, subsystems and components in Naval Aviation with significant accuracy. This is accomplished by accessing the many data collection systems in NALDA and at times cross referencing them between data collection systems. In this thesis, a discussion is presented that explains how the data is collected for the F404 and then extracted for use in the system reliability lower confidence limit model.

C. DATABASE MANAGEMENT SYSTEM 2000 CONCEPTS

In order to understand what benefit the NALDA DBMS provides, one must first understand what kind of data is available, its structure and how it is defined.

1. Data Structure

The data is structured by the individual work unit code (WUC) for each aircraft engine. Each subassembly of the basic engine is a subordinate WUC of the engine WUC, and each component WUC of a subassembly is subordinate to the

subassembly WUC. An example of the hierarchial breakdown of the F404 WUCs is as follows:

WUC	Nomenclature
27400	F404-GE-400 Engine
27410	Fan Module
2741210	Disk, Stage 1 Fan
2741240	Fan Blade, Stage 1 (Set)
27420	High Pressure Compressor Module
2742210	Shaft, Compressor Front
27430	Combustor Module
27440	High Pressor Turbine Module
27450	Low Pressor Turbine Module
27460	Afterburner Module

This WUC relationship is important to recognize. It provides for a useable structured format when requesting NALDA data for analyses.

2. Kinds of Data

The data on the F404 is an excellent example of how the data is stored in a DBMS system. The MDS database contains all maintenance related data elements on every F404 engine in the naval inventory. Example of the data elements in the MDS database are WUC, engine serial number, time since new, malfunction, action taken to repair engine, components removed and replaced, serial number of components removed and replaced (if available), TDC compliance on the subassembly or engine

and the activity that performed the maintenance. An example of an MDS NALDA printout in LOTUS 123 format is provided in Figure 1.

	A	B	C	D	E
1				TIME	REASON
2				SINCE	FOR
3	WUC	NOMENCLATURE	SERNO	NEW	REMOVAL
4					
5	2741000	FAN MODULE	312001	1270	804
6	2741000	FAN MODULE	312002	1040	807
7	2741000	FAN MODULE	312002	1400	807
8	2742000	HPC MODULE	317001	1415	804
9	2742000	HPC MODULE	317002	1154	020
10	2742000	HPC MODULE	317002	1253	185
11	2743000	COMBUSTOR MODULE	322001	1415	190
12	2743000	COMBUSTOR MODULE	322002	1005	812
13	2743000	COMBUSTOR MODULE	322002	1201	804
14	2744000	HPT MODULE	327001	1646	804

Figure 1. Sample LOTUS Spreadsheet of MDS Data

Other databases in NALDA contain significant and important data elements. Examples of these databases are AEMS, DMDS, TDSA and NALCOMIS. The AEMS database is structured by engine serial number, providing data elements of where an engine was installed, repaired, modified and present age in flight hours. An example of NALDA AEMS data providing hours since new on the F404 fan module is provided in Figure 2.

	A	B	C	D
1	Time Since New - AEMS Database			
2				
3	MODEL	SERNO	HOURS	
4				
5	F404GE	312001	2216	
6	F404GE	312002	2651	
7	F404GE	312003	1396	
8	F404GE	312004	2167	
9	F404GE	312005	2525	
10	F404GE	312006	2564	
11	F404GE	312007	1296	
12	F404GE	312009	2361	
13	F404GE	312010	2028	
14	F404GE	312012	2488	
15	F404GE	312013	3371	
16	F404GE	312014	2618	
17	F404GE	312015	2162	
18	F404GE	312016	1519	
19	F404GE	312017	2671	

Figure 2. Sample LOTUS Spreadsheet of AEMS Data

A query is very flexible in that it allows the user to obtain the requested data in a format that is relatively useable without modifications. The data can be stored in many different file formats. Three of the most commonly used formats are LOTUS 123, DBASE, and American Standard Code II (ASCII).

D. NALDA DATA ACCURACY AND INTEGRITY

In general, NALDA is extremely accurate. A typical NALDA database contains millions of data entries, each entry being cross referenced to a system or subsystem. NALDA data must be reviewed with caution because the old adage "garbage in garbage out" would apply nicely. For this reason, a cross check between two different databases would be advisable. The data in this thesis was checked using the MDS and AEMS databases and was found to be extremely accurate.

The data in the MDS file provided all maintenance action performed by module serial number for each module of the F404. This information included codes for reasons for engine removal when the reasons were Foreign Object Damage, No Defect-Removed for Scheduled Maintenance or Removed by Higher Authority, and Internal Failure. These codes and many others were removed from the data prior to actual analysis in an effort to calculate the F404 system reliability lower confidence limit more accurately. The AEMS data was used as a cross check for the MDS data. The AEMS data is a more accurate historical record giving the time at when a module is repaired and the present age of a module. Any MDS data that was in conflict with the AEMS data was adjusted to coincide with the AEMS data in an attempt to represent the actual failure history more accurately.

E. POSSIBLE NALDA DBMS IMPROVEMENTS

The lack of interface between databases prevents quick data screening and formulation. Numerous hours are required to clean up the data and to crosscheck the MDS database with the AEMS database. The time, consumed as a result of the crosscheck, could be eliminated if a linking DBMS function was incorporated into the NALDA system. Quick and efficient crosschecking and structuring of data would allow more efficient use of the NALDA system and potentially more customers should begin to use the NALDA DBMS system.

System accessibility is another area of concern. The time to access the computer and query it for your data is relatively small compared to the time required to download the data. Improvements in modem connectivity would allow more users, because a user could get in and out of the system quicker and retrieve the data at a significantly higher rate than is presently available.

F. SUMMARY

NALDA is a highly capable database management system with almost unlimited applications. It is capable of retrieving and processing very complex queries in support of logistic requirements, performing weapon system reliability analysis and providing raw data in specialized form for special case analysis.

III. DESCRIPTION OF THE LOWER CONFIDENCE LIMIT PROCEDURE

The lower confidence limit procedure used in this thesis was obtained from the thesis written by Yee (Ref A.). The procedure in this thesis uses Lotus 123, in place of the FORTRAN program in Yee's thesis, to compute maximum likelihood estimates for the parameters of interest, and to calculate the lower confidence limits for the F404 engine reliability.

A. INTERVAL ESTIMATE PROCEDURE FOR WEIBULL FAILURE TIMES

Suppose that a series system has k components whose failure times are statistically independent, and that the failure time of the *i-th component* has the Weibull distribution with the scale parameter λ_i and the shape parameter β_i, and $i = 1, 2, \ldots, k$. Then the time to failure of the i-th component, X_i has the density function

$$g_i(x) = \lambda_i^{\beta_i} \beta_i x^{\beta_i - 1} \exp[-(\lambda_i x)^{\beta_i}] \ , \quad x > 0, \ \lambda_i > 0, \ \beta_i > 0 \qquad (3.1)$$

Then the i-th component reliability is

$$R_i(x) = \exp[-(\lambda_i x)^{\beta_i}] \ , \quad x > 0 \ , \qquad (3.2)$$

and the system reliability R_s can be written as

$$R_s(x) = \prod_{i=1}^{k} \exp[-(\lambda_i^{\beta_i} x^{\beta_i})] \quad \textbf{(3.3A)}$$

$$= \exp[-(\sum_{i=1}^{k} \lambda_i^{\beta_i} x^{\beta_i})] \quad \textbf{(3.3B)}$$

$$= \exp[-(\lambda_m^{*} \sum_{i=1}^{k} r_i x^{\beta_i})] \quad \textbf{(3.3C)}$$

where $\lambda_i^* = \lambda_i^{\beta i}$, λ_m^* is the maximum of the λ_i^*, $i = 1, 2, \ldots, k$ and $r_i = \lambda_i^* / \lambda_m^*$. If the β_i's are known, then $X_i^{\beta_i}$ will have an exponential distribution with constant failure rate $\lambda_i^{\beta_i}$. [Bain and Englehardt, 1987]

Suppose β_i**'s** are unknown and $X_{i(1)}, X_{i(2)}, \ldots, X_{i(fi)}$ (f_i represents the total number of failures for the of i-th component) are the order statistics for the first x_i failure times under total test time truncated testing (i.e. testing is completed after a specified amount of total time is accumulated) for the i-th component in the system. The ***maximum likelihood estimates*** β_i and $\hat{\lambda}_i$ for β_i and λ_i , are the solutions for β_i and λ_i , respectively in the Equations (3.4A) and (3.4B). [Bain and Englehardt, p 211, 1991].

$$\frac{\sum_{j=1}^{f_i} X_{i(j)}^{\beta_i} \ln X_{i(j)} + \sum_{j=f_i+1}^{n_i} X_{ij}^{\beta_i} \ln X_{ij}}{\sum_{j=1}^{f_i} X_{i(j)}^{\beta_i} + \sum_{j=f_i+1}^{n_i} X_{ij}^{\beta_i}} - \frac{1}{\beta_i} = \frac{1}{f_i} \sum_{j=1}^{f_i} \ln X_{i(j)} \qquad \textbf{(3.4A)}$$

and

$$\lambda_i^{\beta_i} = \frac{f_i}{\sum_{j=1}^{f_i} X_{i(j)}^{\beta_i} + \sum_{j=f_i+1}^{n_i} X_{ij}^{\beta_i}} \qquad \textbf{(3.4B)}$$

The solution, β_i , is a biased estimator for β_i. Bain and Englehart [p 221, 1991] provides a table of constants $B(n_i)$ which depends on the number of test items n_i such that $\beta_i^* = \beta_i B(n_i)$ is a nearly unbiased estimator for β_i when n_i is sufficiently large. For example, as the number of tested component increases to greater than 120, the ratio of the biased estimate for β_i to the unbiased estimate is more than 0.99.

If n_i items of component i are tested until a total test time T_i has accumulated and f_i is the total number of failures of the *i-th* component, then the total number of failures of the system, F, is

$$F = \sum_{i=1}^{k} f_i \qquad \textbf{(3.5)}$$

Now, let

$$T_{ij}=X_{ij}^{\hat{\beta}_i}\ , \text{ for } i = 1,\ 2,\ \dots,\ k \tag{3.6}$$

$$j = 1,\ 2,\ \dots,\ n_i$$

The distribution of T_{ij} is assumed to be approximately exponential with failure rate $\lambda_i^{\hat{\beta}_i} \equiv \lambda_i^*$ and this feature is used to obtain the lower confidence limit on system reliability. The estimate, $\hat{\lambda}_i^*$, for λ_i^* is given by,

$$\hat{\lambda}_i^* = \frac{f_i}{T_i} \tag{3.7}$$

where $T_i = \sum_{j=1}^{n_i} T_{ij}$, $i=1,\ 2,\ \dots,\ k$. .

In this case, f_i is random and so is F. The following expression

$$2\lambda_m^* \sum_{i=1}^{k} r_i T_i \tag{3.8}$$

has an approximate ***Chi-square*** distribution with 2(F+1) degrees of freedom, where F is the total number of failures of the system defined in Equation (3.5). [Bain and Engelhardt, 1987].

The corresponding approximate 100(1-α)% upper confidence limit for λ_m^* is

$$\hat{\lambda}^*_{m,U(\alpha)} = \frac{\chi_{\alpha,2(F+1)}}{2\sum_{i=1}^{k} r_i T_i} \tag{3.9}$$

where $\chi_{\alpha,2(F+1)}$ is the 100(1-α)th percentile point of a *Chi-square* distribution with 2(F+1) degrees of freedom. It is important to realize that an upper confidence limit for λ_m^* will provide a lower confidence limit for reliability of the system.

The values of the r_i's are unknown in this thesis. They will be estimated by $\hat{r}_i$, a nearly unbiased estimator for r_i [Yee, p 5, 1991],

$$\hat{r}_i = \frac{\hat{\lambda}^*_i}{\hat{\lambda}^*_m} \tag{3.10}$$

,

where, *Let* $\hat{\lambda}^*_m = \max_{all\ i} \hat{\lambda}^*_i$

Using the estimator $\hat{r}_i$ for r_i equation (3.9) becomes

$$\hat{\lambda}^*_{m,U(\alpha)} = \frac{\chi_{\alpha,2(F+1)}}{2\sum_{i=1}^{k} \hat{r}_i T_i} \tag{3.11}$$

which is an approximate upper confidence limit for λ^*_m. The index m denotes the component with the largest value $\hat{\lambda}^*_i$ in the system. The corresponding equation for an approximate 100(1-α)% lower confidence limit on the reliability of a series system is

$$\hat{R}_s(x)_{L(\alpha)} = \exp(-\hat{\lambda}^*_{m,U(\alpha)} \sum_{i=1}^{k} \hat{r}_i x^{\beta_i}) \tag{3.12}$$

B. LOTUS APPLICATION OF WEIBULL DISTRIBUTION MODEL

The computer program "LOTUS 1-2-3" (LOTUS) is a very powerful electronic spreadsheet capable of performing complex numerical calculations quickly and efficiently. LOTUS performs these computations in a logical step-by-step sequence where complex mathematical computations are divided into simple calculations and the final product is the combination of the simple mathematical computation. It is assumed that the reader of this thesis has a basic working knowledge of LOTUS

consisting of basic mathematical expressions and mathematical functions and can understand special LOTUS commands such as the "@IF" command.

The adaptation of the Weibull β equation (Equation 3.4A) to LOTUS in order to calculate the β was relatively simple. Equation (3.4A) was divided into one simple mathematical operation after another, ultimately completing Equation (3.4A) and providing the means to calculate the β. Appendix A is the designed LOTUS spreadsheet without data. In its present form it is capable of calculating β for 28 individualized components with a maximum of five (5) failures per components. The cell formulas for the LOTUS spreadsheet are contained in Appendix B. For clarity, the corresponding LOTUS equations to the Weibull β equation are provided in Appendix C.

C. LOTUS APPLICATION OF LOWER CONFIDENCE LIMIT PROCEDURE

This application is similar to the one discussed in Section B except Equation (3.11) and (3.12) are adapted to LOTUS in order to calculate an approximate $100(1-\alpha)\%$ lower confidence limit. The cell formulas for the LOTUS spreadsheet are provided in Appendix D with the procedures to calculate a chi-square value with 2(F+1) degrees of freedom for 80%, 85%, 90%, 95% and 99% LCL. The corresponding LCL equations are provided in Appendix C. A sample of the Lower Confidence Limit spreadsheet used in this thesis is provided in Figure 3.

SUM(Ri) =	759
SUM (r ^ i*Ti) =	9159085.
SUM(r ^ i) =	1.931125

	FAN	HPC	COMB	HPT	LPT	BURNER
B HAT =	1.256396	1.487985	1.549658	1.758666	1.337816	1.301362
SUM(Ti') ^ B*LnTi' =	16995349	97629829	87179622	6.7E+08	15305243	7623345.
SUM(Ti' ^ B) =	2225744.	12760662	11691900	87727920	2062829.	1063809.
SUM(Ti) ^ B*LnTi =	3084427.	21137811	68403279	1.9E+08	13425058	10847504
SUM(Ti ^ B) =	425930.2	2933263.	9442653.	25199707	1856561.	1530661.
SUM(Ln(Ti)) =	393.0405	530.9685	1155.193	517.5324	1072.997	1365.440
r =	58	77	172	74	163	215
SUM ALL (Ti ^ B) =	2651674.	15693926	21134553	1.1E+08	3919391.	2594471
TOTAL HOURS =	382426	399074	371869	380252	335256	307698
LAMBDA ^ i* =	0.000021	0.000004	0.000008	0.000000	0.000041	0.000082
r ^ i =	0.263947	0.059206	0.098207	0.007907	0.501856	1
r ^ i*Ti =	699903.8	929182.6	2075576.	892980.7	1966971.	2594471

LOWER CONFIDENCE LIMITS FOR ti = 100 to 1000

CHI SQR LCL FOR	80.00%	85.00%	90.00%	95.00%	99.00%
DEGREE FREEDOM=	1520	1520	1520	1520	1520
CHI SQUARE=	1566.424	1577.176	1590.684	1610.699	1648.246
LAMBDA ^ FOR=	0.000085	0.000086	0.000086	0.000087	0.000089
ti					
100	0.923564	0.923060	0.922428	0.921491	0.919736
200	0.814434	0.813288	0.811850	0.809723	0.805749
300	0.698649	0.696932	0.694780	0.691604	0.685684
400	0.586489	0.584345	0.581662	0.577710	0.570367
500	0.483381	0.480975	0.477969	0.473550	0.465370
600	0.392002	0.389491	0.386358	0.381762	0.373288
700	0.313281	0.310795	0.307700	0.303170	0.294852
800	0.247024	0.244665	0.241732	0.237452	0.229625
900	0.192361	0.190197	0.187512	0.183604	0.176491
1000	0.148046	0.146118	0.143731	0.140265	0.133987

Figure 3. Example of the Lower Confidence Limit Spreadsheet

D. SUMMARY

LOTUS is a very powerful tool capable of performing complex mathematical computations. It is widely used in the commercial industry and the Navy, and it is a decision support tool for decisions makers. Separate spreadsheets were developed using Yee's lower confidence limit estimate for reliability to compute; 1) the β value for each module of the F404 engine and 2) LCL for system reliability based on those β. Appendices B and D provide the LOTUS cell formulas used to calculate the β and the LCL for system reliability respectively.

IV. LOTUS DATA RESTRUCTURING AND ANALYSIS

A. DATA RESTRUCTURING

Prior to performing any data analysis, the raw data should be purged of any inappropriate data entries. A sample of the raw data provided by the MDS data base of NALDA is contained in Appendix E. Once the data has been purged of inappropriate data (e.g., No Defect - Removed by Higher Authority), then the data needs to be restructured to fit into the LOTUS spreadsheet.

The data purge and subsequent restructuring is simple to accomplish, and, after completion, it will resemble the data format in Appendix F. The restructured data format provides for a maximum of five (5) or a minimum of zero failures for any one module serial number. Each failure time in the HOURS FIRST/SECOND/THIRD/FOURTH/FIFTH FAILURE columns is the time accumulated in operating time since last failure. These times are the "Ti's" of the LOTUS spreadsheet and corresponding to the X_{ij} in Chapter III of this thesis.

The total hours column of Appendix F is obtained from the AEMS data base of NALDA and the procedure for data processing is simpler than for the MDS data base. The TOTAL HOURS minus the summation of the failure times provides the total time for each serial number that did not experience a failure, "Ti".

FAN Module Beta Value

B HAT=	1.427341		
SUM(Ti') ^ B*LnTi'=	0	B HAT EQ=	ERR
SUM(Ti' ^ B)=	0		
SUM(Ti) ^ B*LnTi=	0	MTBF=	ERR
SUM(Ti ^ B)=	0	Lambda=	ERR
SUM(Ln(Ti))=	0		
r=	0		
SUM ALL (Ti ^ B)=	0		
TOTAL HOURS=	0		

MODEL	SERNO	TIME FIRST FAILURE	TIME SECOND FAILURE	TIME THIRD FAILURE	TIME FOURTH FAILURE	TIME FIFTH FAILURE	TOTAL HOURS
TOTALS		0	0	0	0	0	0

Figure 4. Example of BURNER Module Spreadsheet

B. DATA PROCESSING TO OBTAIN β

The LOTUS spreadsheet is designed for easy data importation. The large shaded area in Figure 4 is the zone that the restructured data is imported into. The method for importing data from one spreadsheet into another in LOTUS is the **/ FILE COMBINE** command. Caution must be observed when specifying the data range for import. If the specified range is too large the spreadsheet will malfunction. A smaller data range could be imported with no affect on the spreadsheet because of the @IF statements imbedded in the spreadsheet. If no data is imported, a zero is assumed for the failure time and/or total hours.

To demonstrate the ease of using of LOTUS, the first 28 lines of data was imported from Appendix F into the β spreadsheet, a sample of the results is provided in Figure 5 and the complete spreadsheet results in Appendix G.

The steps to input data from a data file to the β spreadsheet in order to compute β is relatively easy. Prior to commencing the data transfer steps, place the computer

BURNER Module Beta Value

B HAT=	1.278441		
SUM(Ti') ^ B*LnTi'=	853128.1	B HAT EQ=	0.000000
SUM(Ti' ^ B)=	122903.0		
SUM(Ti) ^ B*LnTi=	2316056.	MTBF=	1164.152
SUM(Ti ^ B)=	325952.5	Lambda=	0.000858
SUM(Ln(Ti))=	339.0328		
r=	54		
SUM ALL (Ti ^ B)=	448855.5		
TOTAL HOURS=	63586		

MODEL	SERNO	TIME FIRST FAILURE	TIME SECOND FAILURE	TIME THIRD FAILURE	TIME FOURTH FAILURE	TIME FIFTH FAILURE	TOTAL HOURS
F404GE	337001	1594					2652
F404GE	337002	91	362	633	386	1168	2967
F404GE	337003	1289	95				1384
F404GE	337004	579	489	105			1691
F404GE	337005	708	1119				1827
F404GE	337006	1117	517				2997
F404GE	337007	1700	21				1910
F404GE	337009	185	1571				1756
F404GE	337010	989	1558				2547
F404GE	337012	2142	370	328	234		3678
F404GE	337013	705	1145				2831
F404GE	337014						1918
F404GE	337015	69	352	444	528		2455
F404GE	337016	591	565				1703
F404GE	337017	2	1963	67			2032
F404GE	337018	1121	484				2655
F404GE	337019	789	2031				3598
F404GE	337020	916	2263				3527
F404GE	337021						1551
F404GE	337022	1533	188				2399
F404GE	337023	1255	1372				3099
F404GE	337024	1694					2946
F404GE	337025	1287					1361
F404GE	337026						760
F404GE	337027						1468
F404GE	337028	1212					1352
F404GE	337030	824	332				1765
F404GE	337031	946	212	1368			2757
TOTALS		23338	17009	2945	1148	1168	63586

Figure 5. Example of BURNER Module Beta Value Spreadsheet with Values

cursor in the upper left hand corner of the data window selected to receive the inputted data. The data transfer steps are:

Step 1. Press SLASH (/) key to call up the menu.

Step 2. Press F for file.

Step 3. Press C for combine.

Step 4. Press C for Copy

Step 5. Press N for Named/Specified Range.

Step 6. Enter the range of the data to be inputted.

Step 7. Select the data file that contains data and press the Enter key.

The computer will automatically copy the data range specified from the data file to the spreadsheet and perform an immediate computation of the "**B HAT EQ**".

The β is easily obtained at this point by inputting values into the "**B HAT**" block and observing the result of the "**B HAT EQ**" block. If the value of the B HAT EQ is negative, then a larger value should be imputed into the B HAT block, and conversely if the B HAT EQ block is positive.

This procedure is repeated until the B HAT EQ block is equal to zero (0). Figure 5 is a sample spreadsheet where the B HAT calculation is completed, B HAT = 1.278441 and the B HAT EQ = 0.000000.

C. LOTUS APPLICATION OF THE LOWER CONFIDENCE LIMIT PROCEDURE

The Lower Confidence Limit (LCL) LOTUS spreadsheet was designed to employ drop in window applications similar to that of the weibull distribution application. The procedure used in subsection B of this chapter to input data is the same with one exception, in step 4 select "add" instead of "copy".

FAN Module Beta Value

B HAT=	1.42734181		
SUM(Ti'^B)*LnTi'=	62954168.116	B HAT EQ=	0.000000
SUM(Ti'^B)=	8224082.0629		
SUM(Ti^B)*LnTi=	10698623.342	MTBF=	4620.221
SUM(Ti^B)=	1472112.7687	Lambda=	0.000216
SUM(Ln(Ti))=	393.04053971		
r=	57		
SUM ALL (Ti^B)=	9696194.8317		
TOTAL HOURS=	382426		

Figure 6. FAN Module Beta Value Calculation Window

The shaded area in the LCL spreadsheet (Figure 7) has the imported data from the shaded area in Figure 6. This sample LCL printout contains calculated confidence limits for the F404 engine at times, ti = 100 to 1000 in increments of 100.

This spreadsheet will allow the user to input the data manually instead of using the data import function in LOTUS. The author realizes this is an alternate method but recommends against it for expediency purposes.

The author realizes not all systems reliability will be calculated in 100 hour increments; therefore the operating time column can be modified to support whatever time the user

SUM(Ri)=	735
SUM (r^i*Ti)=	33950063
SUM(r^i)=	2.405455

	FAN	HPC	COMB	HPT	LPT	BURNER
B HAT=	1.427341	1.624326	1.69191	1.852362	1.435671	1.481682
SUM(Ti') ^ B*LnTi'=	62954168	2.8E+08	2.5E+08	1.4E+09	31829637	28172046
SUM(Ti' ^ B)=	8224082.	36274393	33889343	1.8E+08	4274127.	3902170.
SUM(Ti) ^ B*LnTi=	10698623	56630803	1.9E+08	3.7E+08	27351756	39380210
SUM(Ti ^ B)=	1472112.	7841757.	26512006	50407709	3770078.	5520703.
SUM(Ln(Ti))=	393.0405	523.0114	1135.597	513.4893	1059.016	1324.787
r=	57	75	167	73	159	204
SUM ALL (Ti ^ B)=	9696194.	44116151	60401350	2.3E+08	8044206.	9422874.
TOTAL HOURS=	382426	399074	371869	380252	335256	307698
LAMBDA ^ i*=	0.000005	0.000001	0.000002	0.000000	0.000019	0.000021
r ^ i=	0.271535	0.078526	0.127709	0.014691	0.912992	1
r ^ i*Ti=	2632862.	3464292.	7713823.	3371911.	7344299.	9422874.

LOWER CONFIDENCE LIMITS FOR ti = 100 to 1000

CHI SQR LCL FOR	80.00%	85.00%	90.00%	95.00%	99.00%
DEGREE FREEDOM	1472	1472	1472	1472	1472
CHI SQUARE=	1517.685	1528.266	1541.559	1561.255	1598.205
LAMBDA ^ FOR=	0.000022	0.000022	0.000022	0.000022	0.000023
ti					
100	0.949570	0.949228	0.948798	0.948161	0.946967
200	0.862411	0.861522	0.860405	0.858754	0.855665
300	0.759940	0.758487	0.756666	0.753975	0.748953
400	0.653075	0.651138	0.648713	0.645136	0.638478
500	0.548997	0.546707	0.543843	0.539627	0.531806
600	0.452363	0.449868	0.446753	0.442177	0.433719
700	0.365904	0.363348	0.360162	0.355494	0.346898
800	0.290884	0.288391	0.285289	0.280753	0.272438
900	0.227488	0.225152	0.222251	0.218021	0.210302
1000	0.175156	0.173041	0.170421	0.166611	0.159693

Figure 7. Example of the Lower Confidence Limit Spreadsheet

requires. The user is only required to enter the desired values in the "ti" cells and the spreadsheet will automatically recalculate new LCL for the specified times.

D. SUMMARY

The spreadsheets are very fast and flexible, capable of handling large amounts of data quickly and efficiently. Each spreadsheet functioned flawlessly when the data inputs procedures were performed correctly and the specified input data range did not exceed the receiving data window range. The results are visually easy to read and self-explanatory.

V. DATA ANALYSIS

In this chapter, the data extracted from the NALDA database (Appendix E) was initially structured in accordance with the methods discussed in Chapter IV. The structured data was processed under three increasingly restrictive sets of criteria.

In the initial case (Case 1), all failure data was processed with no restrictions and a LCL was calculated. In the second case (Case 2), the data was reprocessed and all second and subsequent failures that occurred with less than 100 operating hours after repair was removed. In the third case (Case 3) the data was reprocessed and all operating time following the initial failure was eliminated.

A. CASE 1 ANALYSIS

All failure data was used in this case 1 analysis in an effort to calculate realistic lower confidence limits on the F404 reliability. Once restructured the data was entered into the Weibull β equation spreadsheet for each module and the results recorded. The results of the β was than entered into the LCL spreadsheet and the LCL was automatically

SUM(Ri) =	759
SUM (r ^ i*Ti) =	9159085.
SUM(r ^ i) =	1.931125

	FAN	HPC	COMB	HPT	LPT	BURNER
B HAT=	1.256396	1.487985	1.549658	1.758666	1.337816	1.301362
SUM(Ti') ^ B*LnTi'=	16995349	97629829	87179622	6.7E+08	15305243	7623345.
SUM(Ti' ^ B)=	2225744.	12760662	11691900	87727920	2062829.	1063809.
SUM(Ti) ^ B*LnTi=	3084427.	21137811	68403279	1.9E+08	13425058	10847504
SUM(Ti ^ B)=	425930.2	2933263.	9442653.	25199707	1856561.	1530661.
SUM(Ln(Ti))=	393.0405	530.9685	1155.193	517.5324	1072.997	1365.440
r=	58	77	172	74	163	215
SUM ALL (Ti ^ B)=	2651674.	15693926	21134553	1.1E+08	3919391.	2594471
TOTAL HOURS=	382426	399074	371869	380252	335256	307698
LAMBDA ^ i*=	0.000021	0.000004	0.000008	0.000000	0.000041	0.000082
r ^ i=	0.263947	0.059206	0.098207	0.007907	0.501856	1
r ^ i*Ti=	699903.8	929182.6	2075576.	892980.7	1966971.	2594471

LOWER CONFIDENCE LIMITS FOR ti = 100 to 1000

CHI SQR LCL FOR	80.00%	85.00%	90.00%	95.00%	99.00%
DEGREE FREEDOM=	1520	1520	1520	1520	1520
CHI SQUARE=	1566.424	1577.176	1590.684	1610.699	1648.246
LAMBDA ^ FOR=	0.000085	0.000086	0.000086	0.000087	0.000089
ti					
100	0.923564	0.923060	0.922428	0.921491	0.919736
200	0.814434	0.813288	0.811850	0.809723	0.805749
300	0.698649	0.696932	0.694780	0.691604	0.685684
400	0.586489	0.584345	0.581662	0.577710	0.570367
500	0.483381	0.480975	0.477969	0.473550	0.465370
600	0.392002	0.389491	0.386358	0.381762	0.373288
700	0.313281	0.310795	0.307700	0.303170	0.294852
800	0.247024	0.244665	0.241732	0.237452	0.229625
900	0.192361	0.190197	0.187512	0.183604	0.176491
1000	0.148046	0.146118	0.143731	0.140265	0.133987

Figure 8. Results of Case 1 Analysis

calculated. The results are provided in Figure 8. The values calculated for all the raw data indicate a very high reliability for the F404.

SUM(Ri) =	735
SUM (r ^ i*Ti) =	33950063.
SUM(r ^ i) =	2.4054555

	FAN	HPC	COMB	HPT	LPT	BURNER
B HAT =	1.4273418	1.624326	1.69191	1.852362	1.435671	1.4816825
SUM(Ti') ^ B*LnTi' =	62954168.	278172224	253696446	1.37E+09	31829637.	28172046.
SUM(Ti' ^ B) =	8224082.0	36274393.	33889343.	179106679	4274127.7	3902170.9
SUM(Ti) ^ B*LnTi =	10698623.	56630803.	192732057	373305901	27351756.	39380210.
SUM(Ti ^ B) =	1472112.7	7841757.5	26512006.	50407709.	3770078.8	5520703.8
SUM(Ln(Ti)) =	393.04053	523.01141	1135.5977	513.48936	1059.0166	1324.7874
r =	57	75	167	73	159	204
SUM ALL (Ti ^ B) =	9696194.8	44116151.	60401350.	229514389	8044206.5	9422874.8
TOTAL HOURS =	382426	399074	371869	380252	335256	307698
LAMBDA ^ i* =	0.0000058	0.0000017	0.0000027	0.0000003	0.0000197	0.0000216
r ^ i =	0.2715355	0.0785266	0.1277094	0.0146915	0.9129924	1
r ^ i*Ti =	2632862.0	3464292.2	7713823.9	3371911.0	7344299.4	9422874.8

LOWER CONFIDENCE LIMITS FOR ti = 100 to 1000

CHI SQR LCL FOR	80.00%	85.00%	90.00%	95.00%	99.00%
DEGREE FREEDOM =	1472	1472	1472	1472	1472
CHI SQUARE =	1517.6857	1528.2662	1541.5595	1561.2554	1598.2055
LAMBDA ^ FOR =	0.0000223	0.0000225	0.0000227	0.0000229	0.0000235
ti					
100	0.9495709	0.9492284	0.9487983	0.9481614	0.9469676
200	0.8624115	0.8615220	0.8604058	0.8587545	0.8556653
300	0.7599408	0.7584879	0.7566663	0.7539754	0.7489531
400	0.6530757	0.6511387	0.6487133	0.6451363	0.6384788
500	0.5489978	0.5467075	0.5438435	0.5396276	0.5318065
600	0.4523631	0.4498683	0.4467533	0.4421777	0.4337198
700	0.3659042	0.3633486	0.3601629	0.3554942	0.3468983
800	0.2908847	0.2883914	0.2852890	0.2807537	0.2724388
900	0.2274885	0.2251524	0.2222513	0.2180214	0.2103020
1000	0.1751561	0.1730418	0.1704214	0.1666118	0.1596930

Figure 9. Results of Case 2 Analysis

B. CASE 2 ANALYSIS

The data was reprocessed and all second and subsequent failures that occurred with less than 100 operating hours after repair were removed. The new data was entered into LOTUS and the results of the calculations are provided in Figure 9.

The number of failures with less than 100 operating hours was 24 out of 759. This equates to roughly 3.16% of the sample population. A noticeable improvement over Case 1 in confidence limits was observed across the board.

SUM(Ri)=	513
SUM (r^i*Ti)=	1.5E+08
SUM(r^i)=	2.565578

	FAN	HPC	COMB	HPT	LPT	BURNER
B HAT=	1.579045	1.703888	1.90136	1.831144	1.729476	1.707684
SUM(Ti')^B*LnTi'=	1.9E+08	4.7E+08	8.9E+08	1.1E+09	2.3E+08	86450276
SUM(Ti'^B)=	24045174	60092828	1.2E+08	1.4E+08	29490418	11482391
SUM(Ti)^B*LnTi=	29920848	96392189	7.8E+08	2.9E+08	2.1E+08	1.5E+08
SUM(Ti^B)=	4093325.	13294291	1.1E+08	39763820	27893921	20148900
SUM(Ln(Ti))=	337.0790	467.0134	846.7159	458.9652	729.2758	732.0329
r=	48	66	121	65	105	108
SUM ALL (Ti^B)=	28138500	73387119	2.2E+08	1.8E+08	57384339	31631292
TOTAL HOURS=	278702	260135	110563	242851	114506	57259
LAMBDA^i*=	0.000001	0.000000	0.000000	0.000000	0.000001	0.000003
r^i=	0.499612	0.263400	0.159518	0.107140	0.535906	1
r^i*Ti=	14058352	19330234	35438763	19037352	30752645	31631292

LOWER CONFIDENCE LIMITS FOR ti = 100 to 1000

CHI SQR LCL FOR	80.00%	85.00%	90.00%	95.00%	99.00%
DEGREE FREEDOM=	1028	1028	1028	1028	1028
CHI SQUARE=	1066.178	1075.020	1086.129	1102.589	1133.468
LAMBDA ^ FOR=	0.000003	0.000003	0.000003	0.000003	0.000003
ti					
100	0.975324	0.975122	0.974868	0.974492	0.973787
200	0.920031	0.919396	0.918597	0.917416	0.915204
300	0.844573	0.843390	0.841907	0.839715	0.835616
400	0.756489	0.754740	0.752549	0.749314	0.743282
500	0.662252	0.659993	0.657165	0.652997	0.645250
600	0.567308	0.564647	0.561322	0.556431	0.547371
700	0.475980	0.473058	0.469413	0.464064	0.454193
800	0.391430	0.388397	0.384620	0.379091	0.368931
900	0.315707	0.312703	0.308969	0.303518	0.293550
1000	0.249866	0.247008	0.243465	0.238308	0.228925

Figure 10. Results of Case 3 Analysis

C. CASE 3 ANALYSIS

In this case, the data was reprocessed again and all operating time following the first failure was removed to remove the failures caused by maintenance. This analysis was performed in order to more accurately calculate the LCL for reliability when the engine is newly received. The LCL for reliability improved as anticipated from case 1 through case 3. The case 3 analysis results are provided in Figure 10. With all new components and no wear, the 99% LCL for reliability for the F404 is 97.37% at time ti = 100. This is only a small improvement over the 80% LCL of 97.53%.

D. SUMMARY

The analysis of the NALDA data indicates the F404 engine to have a relatively high lower confidence limit for reliability. The case analysis disclosed that as the data was reprocessed under increasingly restrictive criteria, the β value became larger. This increase in β corresponded to a direct increase in the LCL for which each ti value was calculated.

The percent of data removed during the reprocessing of data from case 1 to case 2 equals 3.16%. This figure is relatively small and tends to indicate a relatively high quality of maintenance and repair on the F404 engine. This

small change of input data resulted in a 2.5% increase at ti=100 for the LCL for reliability estimate of the F404.

The percent of data removed during the reprocessing of data from case 2 to case 3 format equals 30.2%. This figure is high and produced only a 3% change in the LCL for reliability estimates. This tends to support the belief that the F404 is an inherently reliable and is in a "as like new condition" after repair with only an negligible degradation in reliability.

VI. SUMMARY, CONCLUSION AND RECOMMENDATIONS

A. SUMMARY

The confidence interval procedures for the reliability of complex systems adapted easily to LOTUS 1-2-3 and performed quickly and efficiently on a personal computer. LOTUS is a very flexible program, allowing the operator to modify a spreadsheet quickly, import or export data ranges effortlessly, and restructure data.

The MDS database of NALDA is extremely capable of providing data in support of complex data analysis; however, the data requested was frequently delayed due to technical support reasons or lack of programming expertise in building data query requests. After receipt of the NALDA data, it required verification with the AEMS database to ensure its accuracy and then restructuring for processing in LOTUS.

The data was processed in accordance with case 1, 2, and 3 criteria and confidence intervals for the reliability of the F404 were obtained. The results of the data indicate the F404 to be an inherently reliable engine performing in a like new condition after repair.

B. CONCLUSIONS

The F404 aircraft engine is a very reliable engine. The results of the analysis support this fact and indicate the fleet repair facilities are maintaining the engines in a like new condition. The NALDA database is very accurate but labor intensive when extracting data for computational purposes. A significant amount of time could be save if NALDA were designed to link two or more databases in order to electronically reprocess data. The inconvenience of having to manually validate and restructure the data will cause many potential users to ignore the NALDA database.

The approximate lower confidence limit procedure for system reliability used in this thesis is capable of performing reliability growth analysis in support of the Component Improvement Program (CIP). It can perform reliability analysis of new complex weapon systems where verification of contractor ability to meet stated system reliability goals. These procedures can also be utilized by program managers or systems engineers and thereby reduce their dependence on the contractor to provide the reliability data.

C. RECOMMENDATIONS

The following recommendations are provided as a result of the research performed in this thesis:

1. Utilize this LCL procedure to perform a verification of contractor supplied reliability analysis in support of new weapons programs and the Component Improvement program (CIP), where critically important decisions for these programs are primarily based on contractor analysis of Navy historical data.

2. Empower NALDA with the ability to link two or more databases and perform verification analysis of the data.

APPENDIX A

SAMPLE LOTUS SPREADSHEET

This a sample LOTUS spreadsheet without data used to calculate β.

FAN Module Beta Value

B HAT=	1.427341		
SUM(Ti')^B*LnTi'=	0	B HAT EQ=	ERR
SUM(Ti'^B)=	0		
SUM(Ti)^B*LnTi=	0	MTBF=	ERR
SUM(Ti^B)=	0	Lambda=	ERR
SUM(Ln(Ti))=	0		
r=	0		
SUM ALL (Ti^B)=	0		
TOTAL HOURS=	0		

MODEL	SERNO	TIME FIRST FAILURE	TIME SECOND FAILURE	TIME THIRD FAILURE	TIME FOURTH FAILURE	TIME FIFTH FAILURE	TOTAL HOURS	Ti^B	Ln(Ti)	Ti^B*LnTi	Ti^B	Ln(Ti)	Ti^B*LnTi
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
TOTALS		0	0	0	0	0	0	0	0	0	0	0	0

Ti^B	Ln(Ti)	Ti^B*LnTi	Ti^B	Ln(Ti)	Ti^B*LnTi	Ti^B	Ln(Ti)	Ti^B*LnTi	Ti'	Ti'^B	Ln Ti'	Ti'^b*LnTi'
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX B

FAN Module Beta Value Spreadsheet Equations

```
D2: ^FAN Module Beta Value
C4: "B HAT=
D4: 1.42734181
B5: "SUM(Ti')^B*LnTi'=
D5: +AA47
F5: 'B HAT EQ=
G5: ((D7+D5)/(D8+D6)-(1/D4)-(1/D10)*D9)
B6: "SUM(Ti'^B)=
D6: +Y47
B7: "SUM(Ti)^B*LnTi=
D7: +K47+N47+Q47+T47+W47
F7: "MTBF=
G7: (((1/D10)*((D8)+(D6))))^(1/D4)
B8: "SUM(Ti^B)=
D8: +I47+L47+O47+R47+U47
F8: " Lambda=
G8: 1/G7
B9: "SUM(Ln(Ti))=
D9: +J47+M47+P47+S47+V47
C10: "r=
D10: @COUNT(C18..G45)
B11: "SUM ALL (Ti^B)=
D11: +D6+D8
B12: "TOTAL HOURS=
D12: +H47
C15: 'TIME
D15: 'TIME
E15: 'TIME
F15: 'TIME
G15: 'TIME
C16: 'FIRST
D16: 'SECOND
E16: 'THIRD
F16: 'FOURTH
G16: 'FIFTH
H16: 'TOTAL
I16: [W11] 'Ti^B
J16: 'Ln(Ti)
K16: 'Ti^B*LnTi
L16: [W11] 'Ti^B
M16: 'Ln(Ti)
```

```
N16: 'Ti^B*LnTi
O16: 'Ti^B
P16: 'Ln(Ti)
Q16: 'Ti^B*LnTi
R16: 'Ti^B
S16: 'Ln(Ti)
T16: 'Ti^B*LnTi
U16: 'Ti^B
V16: 'Ln(Ti)
W16: 'Ti^B*LnTi
X16: 'Ti'
Y16: 'Ti'^B
Z16: 'Ln Ti'
AA16: 'Ti'^b*LnTi'
A17: 'MODEL
B17: "SERNO
C17: 'FAILURE
D17: 'FAILURE
E17: 'FAILURE
F17: 'FAILURE
G17: 'FAILURE
H17: 'HOURS
I18: [W11] @IF(C18>0,C18^$D$4,0)
J18: @IF(C18>0,@LN(C18),0)
K18: +I18*J18
L18: [W11] @IF(D18>0,D18^$D$4,0)
M18: @IF(D18>0,@LN(D18),0)
N18: +L18*M18
O18: @IF(E18>0,E18^$D$4,0)
P18: @IF(E18>0,@LN(E18),0)
Q18: +O18*P18
R18: @IF(F18>0,F18^$D$4,0)
S18: @IF(F18>0,@LN(F18),0)
T18: +R18*S18
U18: @IF(G18>0,G18^$D$4,0)
V18: @IF(G18>0,@LN(G18),0)
W18: +U18*V18
X18: +H18-C18-D18-E18-F18-G18
Y18: @IF(X18>0,X18^$D$4,0)
Z18: @IF(X18>0,@LN(X18),0)
AA18: +Y18*Z18
I19: [W11] @IF(C19>0,C19^$D$4,0)
J19: @IF(C19>0,@LN(C19),0)
K19: +I19*J19
L19: [W11] @IF(D19>0,D19^$D$4,0)
M19: @IF(D19>0,@LN(D19),0)
N19: +L19*M19
O19: @IF(E19>0,E19^$D$4,0)
```

```
P19: @IF(E19>0,@LN(E19),0)
Q19: +O19*P19
R19: @IF(F19>0,F19^$D$4,0)
S19: @IF(F19>0,@LN(F19),0)
T19: +R19*S19
U19: @IF(G19>0,G19^$D$4,0)
V19: @IF(G19>0,@LN(G19),0)
W19: +U19*V19
X19: +H19-C19-D19-E19-F19-G19
Y19: @IF(X19>0,X19^$D$4,0)
Z19: @IF(X19>0,@LN(X19),0)
AA19: +Y19*Z19
I20: [W11] @IF(C20>0,C20^$D$4,0)
J20: @IF(C20>0,@LN(C20),0)
K20: +I20*J20
L20: [W11] @IF(D20>0,D20^$D$4,0)
M20: @IF(D20>0,@LN(D20),0)
N20: +L20*M20
O20: @IF(E20>0,E20^$D$4,0)
P20: @IF(E20>0,@LN(E20),0)
Q20: +O20*P20
R20: @IF(F20>0,F20^$D$4,0)
S20: @IF(F20>0,@LN(F20),0)
T20: +R20*S20
U20: @IF(G20>0,G20^$D$4,0)
V20: @IF(G20>0,@LN(G20),0)
W20: +U20*V20
X20: +H20-C20-D20-E20-F20-G20
Y20: @IF(X20>0,X20^$D$4,0)
Z20: @IF(X20>0,@LN(X20),0)
AA20: +Y20*Z20
I21: [W11] @IF(C21>0,C21^$D$4,0)
J21: @IF(C21>0,@LN(C21),0)
K21: +I21*J21
L21: [W11] @IF(D21>0,D21^$D$4,0)
M21: @IF(D21>0,@LN(D21),0)
N21: +L21*M21
O21: @IF(E21>0,E21^$D$4,0)
P21: @IF(E21>0,@LN(E21),0)
Q21: +O21*P21
R21: @IF(F21>0,F21^$D$4,0)
S21: @IF(F21>0,@LN(F21),0)
T21: +R21*S21
U21: @IF(G21>0,G21^$D$4,0)
V21: @IF(G21>0,@LN(G21),0)
W21: +U21*V21
X21: +H21-C21-D21-E21-F21-G21
Y21: @IF(X21>0,X21^$D$4,0)
```

```
Z21: @IF(X21>0,@LN(X21),0)
AA21: +Y21*Z21
I22: [W11] @IF(C22>0,C22^$D$4,0)
J22: @IF(C22>0,@LN(C22),0)
K22: +I22*J22
L22: [W11] @IF(D22>0,D22^$D$4,0)
M22: @IF(D22>0,@LN(D22),0)
N22: +L22*M22
O22: @IF(E22>0,E22^$D$4,0)
P22: @IF(E22>0,@LN(E22),0)
Q22: +O22*P22
R22: @IF(F22>0,F22^$D$4,0)
S22: @IF(F22>0,@LN(F22),0)
T22: +R22*S22
U22: @IF(G22>0,G22^$D$4,0)
V22: @IF(G22>0,@LN(G22),0)
W22: +U22*V22
X22: +H22-C22-D22-E22-F22-G22
Y22: @IF(X22>0,X22^$D$4,0)
Z22: @IF(X22>0,@LN(X22),0)
AA22: +Y22*Z22
I23: [W11] @IF(C23>0,C23^$D$4,0)
J23: @IF(C23>0,@LN(C23),0)
K23: +I23*J23
L23: [W11] @IF(D23>0,D23^$D$4,0)
M23: @IF(D23>0,@LN(D23),0)
N23: +L23*M23
O23: @IF(E23>0,E23^$D$4,0)
P23: @IF(E23>0,@LN(E23),0)
Q23: +O23*P23
R23: @IF(F23>0,F23^$D$4,0)
S23: @IF(F23>0,@LN(F23),0)
T23: +R23*S23
U23: @IF(G23>0,G23^$D$4,0)
V23: @IF(G23>0,@LN(G23),0)
W23: +U23*V23
X23: +H23-C23-D23-E23-F23-G23
Y23: @IF(X23>0,X23^$D$4,0)
Z23: @IF(X23>0,@LN(X23),0)
AA23: +Y23*Z23
I24: [W11] @IF(C24>0,C24^$D$4,0)
J24: @IF(C24>0,@LN(C24),0)
K24: +I24*J24
L24: [W11] @IF(D24>0,D24^$D$4,0)
M24: @IF(D24>0,@LN(D24),0)
N24: +L24*M24
O24: @IF(E24>0,E24^$D$4,0)
P24: @IF(E24>0,@LN(E24),0)
```

```
Q24: +O24*P24
R24: @IF(F24>0,F24^$D$4,0)
S24: @IF(F24>0,@LN(F24),0)
T24: +R24*S24
U24: @IF(G24>0,G24^$D$4,0)
V24: @IF(G24>0,@LN(G24),0)
W24: +U24*V24
X24: +H24-C24-D24-E24-F24-G24
Y24: @IF(X24>0,X24^$D$4,0)
Z24: @IF(X24>0,@LN(X24),0)
AA24: +Y24*Z24
I25: [W11] @IF(C25>0,C25^$D$4,0)
J25: @IF(C25>0,@LN(C25),0)
K25: +I25*J25
L25: [W11] @IF(D25>0,D25^$D$4,0)
M25: @IF(D25>0,@LN(D25),0)
N25: +L25*M25
O25: @IF(E25>0,E25^$D$4,0)
P25: @IF(E25>0,@LN(E25),0)
Q25: +O25*P25
R25: @IF(F25>0,F25^$D$4,0)
S25: @IF(F25>0,@LN(F25),0)
T25: +R25*S25
U25: @IF(G25>0,G25^$D$4,0)
V25: @IF(G25>0,@LN(G25),0)
W25: +U25*V25
X25: +H25-C25-D25-E25-F25-G25
Y25: @IF(X25>0,X25^$D$4,0)
Z25: @IF(X25>0,@LN(X25),0)
AA25: +Y25*Z25
I26: [W11] @IF(C26>0,C26^$D$4,0)
J26: @IF(C26>0,@LN(C26),0)
K26: +I26*J26
L26: [W11] @IF(D26>0,D26^$D$4,0)
M26: @IF(D26>0,@LN(D26),0)
N26: +L26*M26
O26: @IF(E26>0,E26^$D$4,0)
P26: @IF(E26>0,@LN(E26),0)
Q26: +O26*P26
R26: @IF(F26>0,F26^$D$4,0)
S26: @IF(F26>0,@LN(F26),0)
T26: +R26*S26
U26: @IF(G26>0,G26^$D$4,0)
V26: @IF(G26>0,@LN(G26),0)
W26: +U26*V26
X26: +H26-C26-D26-E26-F26-G26
Y26: @IF(X26>0,X26^$D$4,0)
Z26: @IF(X26>0,@LN(X26),0)
```

```
AA26: +Y26*Z26
I27: [W11] @IF(C27>0,C27^$D$4,0)
J27: @IF(C27>0,@LN(C27),0)
K27: +I27*J27
L27: [W11] @IF(D27>0,D27^$D$4,0)
M27: @IF(D27>0,@LN(D27),0)
N27: +L27*M27
O27: @IF(E27>0,E27^$D$4,0)
P27: @IF(E27>0,@LN(E27),0)
Q27: +O27*P27
R27: @IF(F27>0,F27^$D$4,0)
S27: @IF(F27>0,@LN(F27),0)
T27: +R27*S27
U27: @IF(G27>0,G27^$D$4,0)
V27: @IF(G27>0,@LN(G27),0)
W27: +U27*V27
X27: +H27-C27-D27-E27-F27-G27
Y27: @IF(X27>0,X27^$D$4,0)
Z27: @IF(X27>0,@LN(X27),0)
AA27: +Y27*Z27
I28: [W11] @IF(C28>0,C28^$D$4,0)
J28: @IF(C28>0,@LN(C28),0)
K28: +I28*J28
L28: [W11] @IF(D28>0,D28^$D$4,0)
M28: @IF(D28>0,@LN(D28),0)
N28: +L28*M28
O28: @IF(E28>0,E28^$D$4,0)
P28: @IF(E28>0,@LN(E28),0)
Q28: +O28*P28
R28: @IF(F28>0,F28^$D$4,0)
S28: @IF(F28>0,@LN(F28),0)
T28: +R28*S28
U28: @IF(G28>0,G28^$D$4,0)
V28: @IF(G28>0,@LN(G28),0)
W28: +U28*V28
X28: +H28-C28-D28-E28-F28-G28
Y28: @IF(X28>0,X28^$D$4,0)
Z28: @IF(X28>0,@LN(X28),0)
AA28: +Y28*Z28
I29: [W11] @IF(C29>0,C29^$D$4,0)
J29: @IF(C29>0,@LN(C29),0)
K29: +I29*J29
L29: [W11] @IF(D29>0,D29^$D$4,0)
M29: @IF(D29>0,@LN(D29),0)
N29: +L29*M29
O29: @IF(E29>0,E29^$D$4,0)
P29: @IF(E29>0,@LN(E29),0)
Q29: +O29*P29
```

```
R29: @IF(F29>0,F29^$D$4,0)
S29: @IF(F29>0,@LN(F29),0)
T29: +R29*S29
U29: @IF(G29>0,G29^$D$4,0)
V29: @IF(G29>0,@LN(G29),0)
W29: +U29*V29
X29: +H29-C29-D29-E29-F29-G29
Y29: @IF(X29>0,X29^$D$4,0)
Z29: @IF(X29>0,@LN(X29),0)
AA29: +Y29*Z29
I30: [W11] @IF(C30>0,C30^$D$4,0)
J30: @IF(C30>0,@LN(C30),0)
K30: +I30*J30
L30: [W11] @IF(D30>0,D30^$D$4,0)
M30: @IF(D30>0,@LN(D30),0)
N30: +L30*M30
O30: @IF(E30>0,E30^$D$4,0)
P30: @IF(E30>0,@LN(E30),0)
Q30: +O30*P30
R30: @IF(F30>0,F30^$D$4,0)
S30: @IF(F30>0,@LN(F30),0)
T30: +R30*S30
U30: @IF(G30>0,G30^$D$4,0)
V30: @IF(G30>0,@LN(G30),0)
W30: +U30*V30
X30: +H30-C30-D30-E30-F30-G30
Y30: @IF(X30>0,X30^$D$4,0)
Z30: @IF(X30>0,@LN(X30),0)
AA30: +Y30*Z30
I31: [W11] @IF(C31>0,C31^$D$4,0)
J31: @IF(C31>0,@LN(C31),0)
K31: +I31*J31
L31: [W11] @IF(D31>0,D31^$D$4,0)
M31: @IF(D31>0,@LN(D31),0)
N31: +L31*M31
O31: @IF(E31>0,E31^$D$4,0)
P31: @IF(E31>0,@LN(E31),0)
Q31: +O31*P31
R31: @IF(F31>0,F31^$D$4,0)
S31: @IF(F31>0,@LN(F31),0)
T31: +R31*S31
U31: @IF(G31>0,G31^$D$4,0)
V31: @IF(G31>0,@LN(G31),0)
W31: +U31*V31
X31: +H31-C31-D31-E31-F31-G31
Y31: @IF(X31>0,X31^$D$4,0)
Z31: @IF(X31>0,@LN(X31),0)
AA31: +Y31*Z31
```

```
I32: [W11] @IF(C32>0,C32^$D$4,0)
J32: @IF(C32>0,@LN(C32),0)
K32: +I32*J32
L32: [W11] @IF(D32>0,D32^$D$4,0)
M32: @IF(D32>0,@LN(D32),0)
N32: +L32*M32
O32: @IF(E32>0,E32^$D$4,0)
P32: @IF(E32>0,@LN(E32),0)
Q32: +O32*P32
R32: @IF(F32>0,F32^$D$4,0)
S32: @IF(F32>0,@LN(F32),0)
T32: +R32*S32
U32: @IF(G32>0,G32^$D$4,0)
V32: @IF(G32>0,@LN(G32),0)
W32: +U32*V32
X32: +H32-C32-D32-E32-F32-G32
Y32: @IF(X32>0,X32^$D$4,0)
Z32: @IF(X32>0,@LN(X32),0)
AA32: +Y32*Z32
I33: [W11] @IF(C33>0,C33^$D$4,0)
J33: @IF(C33>0,@LN(C33),0)
K33: +I33*J33
L33: [W11] @IF(D33>0,D33^$D$4,0)
M33: @IF(D33>0,@LN(D33),0)
N33: +L33*M33
O33: @IF(E33>0,E33^$D$4,0)
P33: @IF(E33>0,@LN(E33),0)
Q33: +O33*P33
R33: @IF(F33>0,F33^$D$4,0)
S33: @IF(F33>0,@LN(F33),0)
T33: +R33*S33
U33: @IF(G33>0,G33^$D$4,0)
V33: @IF(G33>0,@LN(G33),0)
W33: +U33*V33
X33: +H33-C33-D33-E33-F33-G33
Y33: @IF(X33>0,X33^$D$4,0)
Z33: @IF(X33>0,@LN(X33),0)
AA33: +Y33*Z33
I34: [W11] @IF(C34>0,C34^$D$4,0)
J34: @IF(C34>0,@LN(C34),0)
K34: +I34*J34
L34: [W11] @IF(D34>0,D34^$D$4,0)
M34: @IF(D34>0,@LN(D34),0)
N34: +L34*M34
O34: @IF(E34>0,E34^$D$4,0)
P34: @IF(E34>0,@LN(E34),0)
Q34: +O34*P34
R34: @IF(F34>0,F34^$D$4,0)
```

```
S34: @IF(F34>0,@LN(F34),0)
T34: +R34*S34
U34: @IF(G34>0,G34^$D$4,0)
V34: @IF(G34>0,@LN(G34),0)
W34: +U34*V34
X34: +H34-C34-D34-E34-F34-G34
Y34: @IF(X34>0,X34^$D$4,0)
Z34: @IF(X34>0,@LN(X34),0)
AA34: +Y34*Z34
I35: [W11] @IF(C35>0,C35^$D$4,0)
J35: @IF(C35>0,@LN(C35),0)
K35: +I35*J35
L35: [W11] @IF(D35>0,D35^$D$4,0)
M35: @IF(D35>0,@LN(D35),0)
N35: +L35*M35
O35: @IF(E35>0,E35^$D$4,0)
P35: @IF(E35>0,@LN(E35),0)
Q35: +O35*P35
R35: @IF(F35>0,F35^$D$4,0)
S35: @IF(F35>0,@LN(F35),0)
T35: +R35*S35
U35: @IF(G35>0,G35^$D$4,0)
V35: @IF(G35>0,@LN(G35),0)
W35: +U35*V35
X35: +H35-C35-D35-E35-F35-G35
Y35: @IF(X35>0,X35^$D$4,0)
Z35: @IF(X35>0,@LN(X35),0)
AA35: +Y35*Z35
I36: [W11] @IF(C36>0,C36^$D$4,0)
J36: @IF(C36>0,@LN(C36),0)
K36: +I36*J36
L36: [W11] @IF(D36>0,D36^$D$4,0)
M36: @IF(D36>0,@LN(D36),0)
N36: +L36*M36
O36: @IF(E36>0,E36^$D$4,0)
P36: @IF(E36>0,@LN(E36),0)
Q36: +O36*P36
R36: @IF(F36>0,F36^$D$4,0)
S36: @IF(F36>0,@LN(F36),0)
T36: +R36*S36
U36: @IF(G36>0,G36^$D$4,0)
V36: @IF(G36>0,@LN(G36),0)
W36: +U36*V36
X36: +H36-C36-D36-E36-F36-G36
Y36: @IF(X36>0,X36^$D$4,0)
Z36: @IF(X36>0,@LN(X36),0)
AA36: +Y36*Z36
I37: [W11] @IF(C37>0,C37^$D$4,0)
J37: @IF(C37>0,@LN(C37),0)
```

```
K37: +I37*J37
L37: [W11] @IF(D37>0,D37^$D$4,0)
M37: @IF(D37>0,@LN(D37),0)
N37: +L37*M37
O37: @IF(E37>0,E37^$D$4,0)
P37: @IF(E37>0,@LN(E37),0)
Q37: +O37*P37
R37: @IF(F37>0,F37^$D$4,0)
S37: @IF(F37>0,@LN(F37),0)
T37: +R37*S37
U37: @IF(G37>0,G37^$D$4,0)
V37: @IF(G37>0,@LN(G37),0)
W37: +U37*V37
X37: +H37-C37-D37-E37-F37-G37
Y37: @IF(X37>0,X37^$D$4,0)
Z37: @IF(X37>0,@LN(X37),0)
AA37: +Y37*Z37
I38: [W11] @IF(C38>0,C38^$D$4,0)
J38: @IF(C38>0,@LN(C38),0)
K38: +I38*J38
L38: [W11] @IF(D38>0,D38^$D$4,0)
M38: @IF(D38>0,@LN(D38),0)
N38: +L38*M38
O38: @IF(E38>0,E38^$D$4,0)
P38: @IF(E38>0,@LN(E38),0)
Q38: +O38*P38
R38: @IF(F38>0,F38^$D$4,0)
S38: @IF(F38>0,@LN(F38),0)
T38: +R38*S38
U38: @IF(G38>0,G38^$D$4,0)
V38: @IF(G38>0,@LN(G38),0)
W38: +U38*V38
X38: +H38-C38-D38-E38-F38-G38
Y38: @IF(X38>0,X38^$D$4,0)
Z38: @IF(X38>0,@LN(X38),0)
AA38: +Y38*Z38
I39: [W11] @IF(C39>0,C39^$D$4,0)
J39: @IF(C39>0,@LN(C39),0)
K39: +I39*J39
L39: [W11] @IF(D39>0,D39^$D$4,0)
M39: @IF(D39>0,@LN(D39),0)
N39: +L39*M39
O39: @IF(E39>0,E39^$D$4,0)
P39: @IF(E39>0,@LN(E39),0)
Q39: +O39*P39
R39: @IF(F39>0,F39^$D$4,0)
S39: @IF(F39>0,@LN(F39),0)
```

```
T39: +R39*S39
U39: @IF(G39>0,G39^$D$4,0)
V39: @IF(G39>0,@LN(G39),0)
W39: +U39*V39
X39: +H39-C39-D39-E39-F39-G39
Y39: @IF(X39>0,X39^$D$4,0)
Z39: @IF(X39>0,@LN(X39),0)
AA39: +Y39*Z39
I40: [W11] @IF(C40>0,C40^$D$4,0)
J40: @IF(C40>0,@LN(C40),0)
K40: +I40*J40
L40: [W11] @IF(D40>0,D40^$D$4,0)
M40: @IF(D40>0,@LN(D40),0)
N40: +L40*M40
O40: @IF(E40>0,E40^$D$4,0)
P40: @IF(E40>0,@LN(E40),0)
Q40: +O40*P40
R40: @IF(F40>0,F40^$D$4,0)
S40: @IF(F40>0,@LN(F40),0)
T40: +R40*S40
U40: @IF(G40>0,G40^$D$4,0)
V40: @IF(G40>0,@LN(G40),0)
W40: +U40*V40
X40: +H40-C40-D40-E40-F40-G40
Y40: @IF(X40>0,X40^$D$4,0)
Z40: @IF(X40>0,@LN(X40),0)
AA40: +Y40*Z40
I41: [W11] @IF(C41>0,C41^$D$4,0)
J41: @IF(C41>0,@LN(C41),0)
K41: +I41*J41
L41: [W11] @IF(D41>0,D41^$D$4,0)
M41: @IF(D41>0,@LN(D41),0)
N41: +L41*M41
O41: @IF(E41>0,E41^$D$4,0)
P41: @IF(E41>0,@LN(E41),0)
Q41: +O41*P41
R41: @IF(F41>0,F41^$D$4,0)
S41: @IF(F41>0,@LN(F41),0)
T41: +R41*S41
U41: @IF(G41>0,G41^$D$4,0)
V41: @IF(G41>0,@LN(G41),0)
W41: +U41*V41
X41: +H41-C41-D41-E41-F41-G41
Y41: @IF(X41>0,X41^$D$4,0)
Z41: @IF(X41>0,@LN(X41),0)
AA41: +Y41*Z41
I42: [W11] @IF(C42>0,C42^$D$4,0)
J42: @IF(C42>0,@LN(C42),0)
```

```
K42: +I42*J42
L42: [W11] @IF(D42>0,D42^$D$4,0)
M42: @IF(D42>0,@LN(D42),0)
N42: +L42*M42
O42: @IF(E42>0,E42^$D$4,0)
P42: @IF(E42>0,@LN(E42),0)
Q42: +O42*P42
R42: @IF(F42>0,F42^$D$4,0)
S42: @IF(F42>0,@LN(F42),0)
T42: +R42*S42
U42: @IF(G42>0,G42^$D$4,0)
V42: @IF(G42>0,@LN(G42),0)
W42: +U42*V42
X42: +H42-C42-D42-E42-F42-G42
Y42: @IF(X42>0,X42^$D$4,0)
Z42: @IF(X42>0,@LN(X42),0)
AA42: +Y42*Z42
I43: [W11] @IF(C43>0,C43^$D$4,0)
J43: @IF(C43>0,@LN(C43),0)
K43: +I43*J43
L43: [W11] @IF(D43>0,D43^$D$4,0)
M43: @IF(D43>0,@LN(D43),0)
N43: +L43*M43
O43: @IF(E43>0,E43^$D$4,0)
P43: @IF(E43>0,@LN(E43),0)
Q43: +O43*P43
R43: @IF(F43>0,F43^$D$4,0)
S43: @IF(F43>0,@LN(F43),0)
T43: +R43*S43
U43: @IF(G43>0,G43^$D$4,0)
V43: @IF(G43>0,@LN(G43),0)
W43: +U43*V43
X43: +H43-C43-D43-E43-F43-G43
Y43: @IF(X43>0,X43^$D$4,0)
Z43: @IF(X43>0,@LN(X43),0)
AA43: +Y43*Z43
I44: [W11] @IF(C44>0,C44^$D$4,0)
J44: @IF(C44>0,@LN(C44),0)
K44: +I44*J44
L44: [W11] @IF(D44>0,D44^$D$4,0)
M44: @IF(D44>0,@LN(D44),0)
N44: +L44*M44
O44: @IF(E44>0,E44^$D$4,0)
P44: @IF(E44>0,@LN(E44),0)
Q44: +O44*P44
R44: @IF(F44>0,F44^$D$4,0)
S44: @IF(F44>0,@LN(F44),0)
T44: +R44*S44
U44: @IF(G44>0,G44^$D$4,0)
V44: @IF(G44>0,@LN(G44),0)
W44: +U44*V44
```

```
X44: +H44-C44-D44-E44-F44-G44
Y44: @IF(X44>0,X44^$D$4,0)
Z44: @IF(X44>0,@LN(X44),0)
AA44: +Y44*Z44
I45: [W11] @IF(C45>0,C45^$D$4,0)
J45: @IF(C45>0,@LN(C45),0)
K45: +I45*J45
L45: [W11] @IF(D45>0,D45^$D$4,0)
M45: @IF(D45>0,@LN(D45),0)
N45: +L45*M45
O45: @IF(E45>0,E45^$D$4,0)
P45: @IF(E45>0,@LN(E45),0)
Q45: +O45*P45
R45: @IF(F45>0,F45^$D$4,0)
S45: @IF(F45>0,@LN(F45),0)
T45: +R45*S45
U45: @IF(G45>0,G45^$D$4,0)
V45: @IF(G45>0,@LN(G45),0)
W45: +U45*V45
X45: +H45-C45-D45-E45-F45-G45
Y45: @IF(X45>0,X45^$D$4,0)
Z45: @IF(X45>0,@LN(X45),0)
AA45: +Y45*Z45
A47: ^TOTALS
C47: @SUM(C18..C45)
D47: @SUM(D18..D45)
E47: @SUM(E18..E45)
F47: @SUM(F18..F45)
G47: @SUM(G18..G45)
H47: @SUM(H18..H45)
I47: [W11] @SUM(I18..I45)
J47: @SUM(J18..J45)
K47: @SUM(K18..K45)
L47: [W11] @SUM(L18..L45)
M47: @SUM(M18..M45)
N47: @SUM(N18..N45)
O47: @SUM(O18..O45)
P47: @SUM(P18..P45)
Q47: @SUM(Q18..Q45)
R47: @SUM(R18..R45)
S47: @SUM(S18..S45)
T47: @SUM(T18..T45)
U47: @SUM(U18..U45)
V47: @SUM(V18..V45)
W47: @SUM(W18..W45)
X47: @SUM(X18..X45)
Y47: @SUM(Y18..Y45)
Z47: @SUM(Z18..Z45)
AA47: @SUM(AA18..AA45)
```

APPENDIX C

LOTUS TO WEIBULL CROSS-REFERENCE

SUM(Ti'^B)*LnTi' $= \sum_{J=1}^{F_i} X_{i(j)}^{\beta_i} \ln X_{i(j)}$

SUM(Ti'^B) $= \sum_{j=1}^{f_i} X_{i(j)}^{\beta_i}$

SUM(Ti^B)*LnTi $= \sum_{j=f_i+1}^{n_i} X_{ij}^{\beta_i} \ln X_{ij}$

SUM(Ti^B) $= \sum_{j=f_i+1}^{n_i} X_{ij}^{\beta_i}$

SUM(Ln(Ti)) $= \sum_{j=1}^{f_i} \ln X_{i(j)}$

SUM(r^i*Ti) $= \sum_{i=1}^{k} \hat{r}_i T_i$

LAMBDA ^ FOR $= \hat{\lambda}_{m,U(\alpha)}$

CHI SQUARE $= \chi_{\alpha, 2(F+1)}$

r = Total Number of Failures

APPENDIX D

Lower Confidence Limit Spreadsheet Equations

```
C2: 'SUM(Ri)=
E2: @SUM(B14..G14)
C3: 'SUM (r^i*Ti)=
E3: @SUM(B20..G20)
C4: 'SUM(r^i)=
E4: @SUM(B19..G19)
B7: ^   FAN
C7: ^   HPC
D7: ^  COMB
E7: ^   HPT
F7: ^   LPT
G7: ^  BURNER
A8: [W17] "  B HAT=
A9: [W17] "SUM(Ti')^B*LnTi'=
A10: [W17] "SUM(Ti'^B)=
A11: [W17] "SUM(Ti)^B*LnTi=
A12: [W17] "SUM(Ti^B)=
A13: [W17] "SUM(Ln(Ti))=
A14: [W17] "r=
A15: [W17] "SUM ALL (Ti^B)=
A16: [W17] "TOTAL HOURS=
A18: [W17] "LAMBDA^i*=
B18: +B14/B15
C18: +C14/C15
D18: +D14/D15
E18: +E14/E15
F18: +F14/F15
G18: +G14/G15
A19: [W17] "r^i=
B19: +B18/$G$18
C19: +C18/$G$18
D19: +D18/$G$18
E19: +E18/$G$18
F19: +F18/$G$18
G19: +G18/$G$18
A20: [W17] "r^i*Ti=
B20: +B19*B15
C20: +C19*C15
D20: +D19*D15
E20: +E19*E15
F20: +F19*F15
G20: +G19*G15
B23: ^LOWER CONFIDENCE LIMITS FOR ti = 100 to 1000
A26: [W17] "CHI SQR LCL FOR
```

```
B26: (P2) 0.8
C26: (P2) 0.85
D26: (P2) 0.9
E26: (P2) 0.95
F26: (P2) 0.99
A27: [W17] "DEGREE FREEDOM=
B27: 2*(1+$E$2)
C27: 2*(1+$E$2)
D27: 2*(1+$E$2)
E27: 2*(1+$E$2)
F27: 2*(1+$E$2)
A28: [W17] "CHI SQUARE=
B28: +B27+0.842*((2*B27)^(1/2))
C28: +C27+1.037*((2*C27)^(1/2))
D28: +D27+1.282*((2*D27)^(1/2))
E28: +E27+1.645*((2*E27)^(1/2))
F28: +F27+2.326*((2*F27)^(1/2))
A29: [W17] "LAMBDA ^ FOR=
B29: +B28/(2*$E$3)
C29: +C28/(2*$E$3)
D29: +D28/(2*$E$3)
E29: +E28/(2*$E$3)
F29: +F28/(2*$E$3)
A31: [W17] 'OPERATING TIME (ti)
B31: (P2) 0.8
C31: (P2) 0.85
D31: (P2) 0.9
E31: (P2) 0.95
F31: (P2) 0.99
A32: [W17] 100
B32: @EXP(-$B$29*($B$19*($A$32^$B$8)+$C$19*($A$32^$C$8)+

$D$19*($A$32^$D$8)+$E$19*($A$32^$E$8)+$F$19*($A$32^$F$8)+
     $G$19*($A$32^$G$8)))
C32: @EXP(-$C$29*($B$19*(A32^$B$8)+$C$19*(A32^$C$8)+
     $D$19*(A32^$D$8)+$E$19*(A32^$E$8)+$F$19*(A32^$F$8)+
     $G$19*(A32^$G$8)))
D32: @EXP(-$D$29*($B$19*(A32^$B$8)+$C$19*(A32^$C$8)+
     $D$19*(A32^$D$8)+$E$19*(A32^$E$8)+$F$19*(A32^$F$8)+
     $G$19*(A32^$G$8)))
E32: @EXP(-$E$29*($B$19*(A32^$B$8)+$C$19*(A32^$C$8)+
     $D$19*(A32^$D$8)+$E$19*(A32^$E$8)+$F$19*(A32^$F$8)+
     $G$19*(A32^$G$8)))
F32: @EXP(-$F$29*($B$19*(A32^$B$8)+$C$19*(A32^$C$8)+
     $D$19*(A32^$D$8)+$E$19*(A32^$E$8)+$F$19*(A32^$F$8)+
     $G$19*(A32^$G$8)))
A33: [W17] +A32+100
B33: @EXP(-$B$29*($B$19*(A33^$B$8)+$C$19*(A33^$C$8)+
     $D$19*(A33^$D$8)+$E$19*(A33^$E$8)+$F$19*(A33^$F$8)+
     $G$19*(A33^$G$8)))
C33: @EXP(-$C$29*($B$19*(A33^$B$8)+$C$19*(A33^$C$8)+
```

```
        $D$19*(A33^$D$8)+$E$19*(A33^$E$8)+$F$19*(A33^$F$8)+
        $G$19*(A33^$G$8)))
D33: @EXP(-$D$29*($B$19*(A33^$B$8)+$C$19*(A33^$C$8)+
        $D$19*(A33^$D$8)+$E$19*(A33^$E$8)+$F$19*(A33^$F$8)+
        $G$19*(A33^$G$8)))
E33: @EXP(-$E$29*($B$19*(A33^$B$8)+$C$19*(A33^$C$8)+
        $D$19*(A33^$D$8)+$E$19*(A33^$E$8)+$F$19*(A33^$F$8)+
        $G$19*(A33^$G$8)))
F33: @EXP(-$F$29*($B$19*(A33^$B$8)+$C$19*(A33^$C$8)+
        $D$19*(A33^$D$8)+$E$19*(A33^$E$8)+$F$19*(A33^$F$8)+
        $G$19*(A33^$G$8)))
A34: [W17] +A33+100
B34: @EXP(-$B$29*($B$19*(A34^$B$8)+$C$19*(A34^$C$8)+
        $D$19*(A34^$D$8)+$E$19*(A34^$E$8)+$F$19*(A34^$F$8)+
        $G$19*(A34^$G$8)))
C34: @EXP(-$C$29*($B$19*(A34^$B$8)+$C$19*(A34^$C$8)+
        $D$19*(A34^$D$8)+$E$19*(A34^$E$8)+$F$19*(A34^$F$8)+
        $G$19*(A34^$G$8)))
D34: @EXP(-$D$29*($B$19*(A34^$B$8)+$C$19*(A34^$C$8)+
        $D$19*(A34^$D$8)+$E$19*(A34^$E$8)+$F$19*(A34^$F$8)+
        $G$19*(A34^$G$8)))
E34: @EXP(-$E$29*($B$19*(A34^$B$8)+$C$19*(A34^$C$8)+
        $D$19*(A34^$D$8)+$E$19*(A34^$E$8)+$F$19*(A34^$F$8)+
        $G$19*(A34^$G$8)))
F34: @EXP(-$F$29*($B$19*(A34^$B$8)+$C$19*(A34^$C$8)+
        $D$19*(A34^$D$8)+$E$19*(A34^$E$8)+$F$19*(A34^$F$8)+
        $G$19*(A34^$G$8)))
A35: [W17] +A34+100
B35: @EXP(-$B$29*($B$19*(A35^$B$8)+$C$19*(A35^$C$8)+
        $D$19*(A35^$D$8)+$E$19*(A35^$E$8)+$F$19*(A35^$F$8)+
        $G$19*(A35^$G$8)))
C35: @EXP(-$C$29*($B$19*(A35^$B$8)+$C$19*(A35^$C$8)+
        $D$19*(A35^$D$8)+$E$19*(A35^$E$8)+$F$19*(A35^$F$8)+
        $G$19*(A35^$G$8)))
D35: @EXP(-$D$29*($B$19*(A35^$B$8)+$C$19*(A35^$C$8)+
        $D$19*(A35^$D$8)+$E$19*(A35^$E$8)+$F$19*(A35^$F$8)+
        $G$19*(A35^$G$8)))
E35: @EXP(-$E$29*($B$19*(A35^$B$8)+$C$19*(A35^$C$8)+
        $D$19*(A35^$D$8)+$E$19*(A35^$E$8)+$F$19*(A35^$F$8)+
        $G$19*(A35^$G$8)))
F35: @EXP(-$F$29*($B$19*(A35^$B$8)+$C$19*(A35^$C$8)+
        $D$19*(A35^$D$8)+$E$19*(A35^$E$8)+$F$19*(A35^$F$8)+
        $G$19*(A35^$G$8)))
A36: [W17] +A35+100
B36: @EXP(-$B$29*($B$19*(A36^$B$8)+$C$19*(A36^$C$8)+
        $D$19*(A36^$D$8)+$E$19*(A36^$E$8)+$F$19*(A36^$F$8)+
        $G$19*(A36^$G$8)))
C36: @EXP(-$C$29*($B$19*(A36^$B$8)+$C$19*(A36^$C$8)+
        $D$19*(A36^$D$8)+$E$19*(A36^$E$8)+$F$19*(A36^$F$8)+
        $G$19*(A36^$G$8)))
D36: @EXP(-$D$29*($B$19*(A36^$B$8)+$C$19*(A36^$C$8)+
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     $D$19*(A36^$D$8)+$E$19*(A36^$E$8)+$F$19*(A36^$F$8)+
     $G$19*(A36^$G$8)))
E36: @EXP(-$E$29*($B$19*(A36^$B$8)+$C$19*(A36^$C$8)+
     $D$19*(A36^$D$8)+$E$19*(A36^$E$8)+$F$19*(A36^$F$8)+
     $G$19*(A36^$G$8)))
F36: @EXP(-$F$29*($B$19*(A36^$B$8)+$C$19*(A36^$C$8)+
     $D$19*(A36^$D$8)+$E$19*(A36^$E$8)+$F$19*(A36^$F$8)+
     $G$19*(A36^$G$8)))
A37: [W17] +A36+100
B37: @EXP(-$B$29*($B$19*(A37^$B$8)+$C$19*(A37^$C$8)+
     $D$19*(A37^$D$8)+$E$19*(A37^$E$8)+$F$19*(A37^$F$8)+
     $G$19*(A37^$G$8)))
C37: @EXP(-$C$29*($B$19*(A37^$B$8)+$C$19*(A37^$C$8)+
     $D$19*(A37^$D$8)+$E$19*(A37^$E$8)+$F$19*(A37^$F$8)+
     $G$19*(A37^$G$8)))
D37: @EXP(-$D$29*($B$19*(A37^$B$8)+$C$19*(A37^$C$8)+
     $D$19*(A37^$D$8)+$E$19*(A37^$E$8)+$F$19*(A37^$F$8)+
     $G$19*(A37^$G$8)))
E37: @EXP(-$E$29*($B$19*(A37^$B$8)+$C$19*(A37^$C$8)+
     $D$19*(A37^$D$8)+$E$19*(A37^$E$8)+$F$19*(A37^$F$8)+
     $G$19*(A37^$G$8)))
F37: @EXP(-$F$29*($B$19*(A37^$B$8)+$C$19*(A37^$C$8)+
     $D$19*(A37^$D$8)+$E$19*(A37^$E$8)+$F$19*(A37^$F$8)+
     $G$19*(A37^$G$8)))
A38: [W17] +A37+100
B38: @EXP(-$B$29*($B$19*(A38^$B$8)+$C$19*(A38^$C$8)+
     $D$19*(A38^$D$8)+$E$19*(A38^$E$8)+$F$19*(A38^$F$8)+
     $G$19*(A38^$G$8)))
C38: @EXP(-$C$29*($B$19*(A38^$B$8)+$C$19*(A38^$C$8)+
     $D$19*(A38^$D$8)+$E$19*(A38^$E$8)+$F$19*(A38^$F$8)+
     $G$19*(A38^$G$8)))
D38: @EXP(-$D$29*($B$19*(A38^$B$8)+$C$19*(A38^$C$8)+
     $D$19*(A38^$D$8)+$E$19*(A38^$E$8)+$F$19*(A38^$F$8)+
     $G$19*(A38^$G$8)))
E38: @EXP(-$E$29*($B$19*(A38^$B$8)+$C$19*(A38^$C$8)+
     $D$19*(A38^$D$8)+$E$19*(A38^$E$8)+$F$19*(A38^$F$8)+
     $G$19*(A38^$G$8)))
F38: @EXP(-$F$29*($B$19*(A38^$B$8)+$C$19*(A38^$C$8)+
     $D$19*(A38^$D$8)+$E$19*(A38^$E$8)+$F$19*(A38^$F$8)+
     $G$19*(A38^$G$8)))
A39: [W17] +A38+100
B39: @EXP(-$B$29*($B$19*(A39^$B$8)+$C$19*(A39^$C$8)+
     $D$19*(A39^$D$8)+$E$19*(A39^$E$8)+$F$19*(A39^$F$8)+
     $G$19*(A39^$G$8)))
C39: @EXP(-$C$29*($B$19*(A39^$B$8)+$C$19*(A39^$C$8)+
     $D$19*(A39^$D$8)+$E$19*(A39^$E$8)+$F$19*(A39^$F$8)+
     $G$19*(A39^$G$8)))
D39: @EXP(-$D$29*($B$19*(A39^$B$8)+$C$19*(A39^$C$8)+
     $D$19*(A39^$D$8)+$E$19*(A39^$E$8)+$F$19*(A39^$F$8)+
     $G$19*(A39^$G$8)))
E39: @EXP(-$E$29*($B$19*(A39^$B$8)+$C$19*(A39^$C$8)+
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       $D$19*(A39^$D$8)+$E$19*(A39^$E$8)+$F$19*(A39^$F$8)+
       $G$19*(A39^$G$8)))
F39:   @EXP(-$F$29*($B$19*(A39^$B$8)+$C$19*(A39^$C$8)+
       $D$19*(A39^$D$8)+$E$19*(A39^$E$8)+$F$19*(A39^$F$8)+
       $G$19*(A39^$G$8)))
A40:   [W17] +A39+100
B40:   @EXP(-$B$29*($B$19*(A40^$B$8)+$C$19*(A40^$C$8)+
       $D$19*(A40^$D$8)+$E$19*(A40^$E$8)+$F$19*(A40^$F$8)+
       $G$19*(A40^$G$8)))
C40:   @EXP(-$C$29*($B$19*(A40^$B$8)+$C$19*(A40^$C$8)+
       $D$19*(A40^$D$8)+$E$19*(A40^$E$8)+$F$19*(A40^$F$8)+
       $G$19*(A40^$G$8)))
D40:   @EXP(-$D$29*($B$19*(A40^$B$8)+$C$19*(A40^$C$8)+
       $D$19*(A40^$D$8)+$E$19*(A40^$E$8)+$F$19*(A40^$F$8)+
       $G$19*(A40^$G$8)))
E40:   @EXP(-$E$29*($B$19*(A40^$B$8)+$C$19*(A40^$C$8)+
       $D$19*(A40^$D$8)+$E$19*(A40^$E$8)+$F$19*(A40^$F$8)+
       $G$19*(A40^$G$8)))
F40:   @EXP(-$F$29*($B$19*(A40^$B$8)+$C$19*(A40^$C$8)+
       $D$19*(A40^$D$8)+$E$19*(A40^$E$8)+$F$19*(A40^$F$8)+
       $G$19*(A40^$G$8)))
A41:   [W17] +A40+100
B41:   @EXP(-$B$29*($B$19*(A41^$B$8)+$C$19*(A41^$C$8)+
       $D$19*(A41^$D$8)+$E$19*(A41^$E$8)+$F$19*(A41^$F$8)+
       $G$19*(A41^$G$8)))
C41:   @EXP(-$C$29*($B$19*(A41^$B$8)+$C$19*(A41^$C$8)+
       $D$19*(A41^$D$8)+$E$19*(A41^$E$8)+$F$19*(A41^$F$8)+
       $G$19*(A41^$G$8)))
D41:   @EXP(-$D$29*($B$19*(A41^$B$8)+$C$19*(A41^$C$8)+
       $D$19*(A41^$D$8)+$E$19*(A41^$E$8)+$F$19*(A41^$F$8)+
       $G$19*(A41^$G$8)))
E41:   @EXP(-$E$29*($B$19*(A41^$B$8)+$C$19*(A41^$C$8)+
       $D$19*(A41^$D$8)+$E$19*(A41^$E$8)+$F$19*(A41^$F$8)+
       $G$19*(A41^$G$8)))
F41:   @EXP(-$F$29*($B$19*(A41^$B$8)+$C$19*(A41^$C$8)+
       $D$19*(A41^$D$8)+$E$19*(A41^$E$8)+$F$19*(A41^$F$8)+
       $G$19*(A41^$G$8)))
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APPENDIX E

SAMPLE MDS DATA PRINTOUT

This is a sample Maintenance Data System (MDS) printout for the AFTERBURNER Module providing failure data history by module serial number.

WUC	NOMENCLATURE	SERIAL #	REASON FOR REMOVAL	DISCRIPTION	TIME SINCE NEW
2746000	AFTERBURNER MODULE	322996	190	CRACKED,CRAZED	950
2746000	AFTERBURNER MODULE	323746	807	NO DEFECT-REM BY HIGHER AUTHORITY	1210
2746000	AFTERBURNER MODULE	332013	135	BINDING STUCK OR JAMMED	2811
2746000	AFTERBURNER MODULE	332422	117	DETERIORATED/ERODED	509
2746000	AFTERBURNER MODULE	332422	093	MISSING PARTS	509
2746000	AFTERBURNER MODULE	332626	804	NO DEFECT-REM FOR SCHED MAINTENANC	1741
2746000	AFTERBURNER MODULE	332883	804	NO DEFECT-REM FOR SCHED MAINTENANC	3487
2746000	AFTERBURNER MODULE	337001	804	NO DEFECT-REM FOR SCHED MAINTENANC	149
2746000	AFTERBURNER MODULE	337001	020	WORN,STRIPPED,CHAFFED,FRAYED	1594
2746000	AFTERBURNER MODULE	337001	070	BROKEN,BURST,CUT,TORN	1659
2746000	AFTERBURNER MODULE	337002	190	CRACKED,CRAZED	91
2746000	AFTERBURNER MODULE	337002	190	CRACKED,CRAZED	453
2746000	AFTERBURNER MODULE	337002	190	CRACKED,CRAZED	1086
2746000	AFTERBURNER MODULE	337002	020	WORN,STRIPPED,CHAFFED,FRAYED	1472
2746000	AFTERBURNER MODULE	337002	416	OUT OF ROUND	2640
2746000	AFTERBURNER MODULE	337003	135	BINDING STUCK OR JAMMED	1289
2746000	AFTERBURNER MODULE	337004	190	CRACKED,CRAZED	579
2746000	AFTERBURNER MODULE	337004	190	CRACKED,CRAZED	1068
2746000	AFTERBURNER MODULE	337004	561	UNABLE TO ADJUST LIMITS	1173
2746000	AFTERBURNER MODULE	337005	190	CRACKED,CRAZED	708
2746000	AFTERBURNER MODULE	337006	190	CRACKED,CRAZED	1117
2746000	AFTERBURNER MODULE	337006	020	WORN,STRIPPED,CHAFFED,FRAYED	1117
2746000	AFTERBURNER MODULE	337006	190	CRACKED,CRAZED	1634
2746000	AFTERBURNER MODULE	337007	804	NO DEFECT-REM FOR SCHED MAINTENANC	598
2746000	AFTERBURNER MODULE	337007	190	CRACKED,CRAZED	1700
2746000	AFTERBURNER MODULE	337009	190	CRACKED,CRAZED	185
2746000	AFTERBURNER MODULE	337010	190	CRACKED,CRAZED	989
2746000	AFTERBURNER MODULE	337010	804	NO DEFECT-REM FOR SCHED MAINTENANC	2146
2746000	AFTERBURNER MODULE	337010	020	WORN,STRIPPED,CHAFFED,FRAYED	2576
2746000	AFTERBURNER MODULE	337012	190	CRACKED,CRAZED	2142
2746000	AFTERBURNER MODULE	337012	070	BROKEN,BURST,CUT,TORN	2512
2746000	AFTERBURNER MODULE	337012	070	BROKEN,BURST,CUT,TORN	2840
2746000	AFTERBURNER MODULE	337012	190	CRACKED,CRAZED	4074
2746000	AFTERBURNER MODULE	337013	190	CRACKED,CRAZED	705
2746000	AFTERBURNER MODULE	337013	780	BENT,BUCKLED,DENTED,ETC.	1850
2746000	AFTERBURNER MODULE	337013	135	BINDING STUCK OR JAMMED	1895
2746000	AFTERBURNER MODULE	337015	135	BINDING STUCK OR JAMMED	69

WUC	NOMENCLATURE	SERIAL #	REASON FOR REMOVAL	DISCRIPTION	TIME SINCE NEW
2746000	AFTERBURNER MODULE	337015	020	WORN,STRIPPED,CHAFFED,FRAYED	96
2746000	AFTERBURNER MODULE	337015	135	BINDING STUCK OR JAMMED	421
2746000	AFTERBURNER MODULE	337015	190	CRACKED,CRAZED	865
2746000	AFTERBURNER MODULE	337015	020	WORN,STRIPPED,CHAFFED,FRAYED	1393
2746000	AFTERBURNER MODULE	337016	190	CRACKED,CRAZED	591
2746000	AFTERBURNER MODULE	337017	190	CRACKED,CRAZED	2
2746000	AFTERBURNER MODULE	337017	804	NO DEFECT-REM FOR SCHED MAINTENANC	1213
2746000	AFTERBURNER MODULE	337017	190	CRACKED,CRAZED	1965
2746000	AFTERBURNER MODULE	337017	190	CRACKED,CRAZED	1966
2746000	AFTERBURNER MODULE	337018	020	WORN,STRIPPED,CHAFFED,FRAYED	1121
2746000	AFTERBURNER MODULE	337018	070	BROKEN,BURST,CUT,TORN	1605
2746000	AFTERBURNER MODULE	337019	190	CRACKED,CRAZED	789
2746000	AFTERBURNER MODULE	337019	020	WORN,STRIPPED,CHAFFED,FRAYED	2820
2746000	AFTERBURNER MODULE	337020	190	CRACKED,CRAZED	916
2746000	AFTERBURNER MODULE	337020	780	BENT,BUCKLED,DENTED,ETC.	3179
2746000	AFTERBURNER MODULE	337020	190	CRACKED,CRAZED	4247
2746000	AFTERBURNER MODULE	337022	190	CRACKED,CRAZED	1533
2746000	AFTERBURNER MODULE	337022	295	FAILS CHECK/TEST	1721
2746000	AFTERBURNER MODULE	337023	170	CORRODED	1255
2746000	AFTERBURNER MODULE	337023	070	BROKEN,BURST,CUT,TORN	2627
2746000	AFTERBURNER MODULE	337024	804	NO DEFECT-REM FOR SCHED MAINTENANC	1190
2746000	AFTERBURNER MODULE	337024	020	WORN,STRIPPED,CHAFFED,FRAYED	1694
2746000	AFTERBURNER MODULE	337024	093	MISSING PARTS	2315
2746000	AFTERBURNER MODULE	337025	803	NO DEFECT-REMOVED FOR TIME CHANGE	876
2746000	AFTERBURNER MODULE	337025	190	CRACKED,CRAZED	1287
2746000	AFTERBURNER MODULE	337025	804	NO DEFECT-REM FOR SCHED MAINTENANC	1287
2746000	AFTERBURNER MODULE	337027	804	NO DEFECT-REM FOR SCHED MAINTENANC	1986
2746000	AFTERBURNER MODULE	337028	804	NO DEFECT-REM FOR SCHED MAINTENANC	410
2746000	AFTERBURNER MODULE	337028	020	WORN,STRIPPED,CHAFFED,FRAYED	2112
2746000	AFTERBURNER MODULE	337030	190	CRACKED,CRAZED	824
2746000	AFTERBURNER MODULE	337030	020	WORN,STRIPPED,CHAFFED,FRAYED	1156
2746000	AFTERBURNER MODULE	337030	020	WORN,STRIPPED,CHAFFED,FRAYED	4746
2746000	AFTERBURNER MODULE	337031	070	BROKEN,BURST,CUT,TORN	946
2746000	AFTERBURNER MODULE	337031	070	BROKEN,BURST,CUT,TORN	1158
2746000	AFTERBURNER MODULE	337031	190	CRACKED,CRAZED	2526
2746000	AFTERBURNER MODULE	337033	190	CRACKED,CRAZED	904
2746000	AFTERBURNER MODULE	337033	093	MISSING PARTS	1246

WUC	NOMENCLATURE	SERIAL #	REASON FOR REMOVAL	DISCRIPTION	TIME SINCE NEW
2746000	AFTERBURNER MODULE	337033	190	CRACKED,CRAZED	1516
2746000	AFTERBURNER MODULE	337035	190	CRACKED,CRAZED	1446
2746000	AFTERBURNER MODULE	337035	190	CRACKED,CRAZED	1706
2746000	AFTERBURNER MODULE	337035	190	CRACKED,CRAZED	2036
2746000	AFTERBURNER MODULE	337036	190	CRACKED,CRAZED	2233
2746000	AFTERBURNER MODULE	337037	020	WORN,STRIPPED,CHAFFED,FRAYED	1126
2746000	AFTERBURNER MODULE	337037	190	CRACKED,CRAZED	1520
2746000	AFTERBURNER MODULE	337040	190	CRACKED,CRAZED	898
2746000	AFTERBURNER MODULE	337040	780	BENT,BUCKLED,DENTED,ETC.	9999
2746000	AFTERBURNER MODULE	337042	381	LEAKING-INTERNAL OR EXTERNAL	1430
2746000	AFTERBURNER MODULE	337042	381	LEAKING-INTERNAL OR EXTERNAL	1430
2746000	AFTERBURNER MODULE	337042	190	CRACKED,CRAZED	1930
2746000	AFTERBURNER MODULE	337043	020	WORN,STRIPPED,CHAFFED,FRAYED	112
2746000	AFTERBURNER MODULE	337043	190	CRACKED,CRAZED	883
2746000	AFTERBURNER MODULE	337043	190	CRACKED,CRAZED	1010
2746000	AFTERBURNER MODULE	337044	190	CRACKED,CRAZED	640
2746000	AFTERBURNER MODULE	337044	190	CRACKED,CRAZED	2001
2746000	AFTERBURNER MODULE	337045	190	CRACKED,CRAZED	1566
2746000	AFTERBURNER MODULE	337045	020	WORN,STRIPPED,CHAFFED,FRAYED	3043
2746000	AFTERBURNER MODULE	337046	190	CRACKED,CRAZED	677
2746000	AFTERBURNER MODULE	337046	804	NO DEFECT-REM FOR SCHED MAINTENANC	1687
2746000	AFTERBURNER MODULE	337046	780	BENT,BUCKLED,DENTED,ETC.	1929
2746000	AFTERBURNER MODULE	337048	020	WORN,STRIPPED,CHAFFED,FRAYED	1576
2746000	AFTERBURNER MODULE	337048	807	NO DEFECT-REM BY HIGHER AUTHORITY	1576
2746000	AFTERBURNER MODULE	337048	804	NO DEFECT-REM FOR SCHED MAINTENANC	1797
2746000	AFTERBURNER MODULE	337049	803	NO DEFECT-REMOVED FOR TIME CHANGE	1037
2746000	AFTERBURNER MODULE	337049	190	CRACKED,CRAZED	1191
2746000	AFTERBURNER MODULE	337049	804	NO DEFECT-REM FOR SCHED MAINTENANC	2003
2746000	AFTERBURNER MODULE	337050	807	NO DEFECT-REM BY HIGHER AUTHORITY	988
2746000	AFTERBURNER MODULE	337052	020	WORN,STRIPPED,CHAFFED,FRAYED	734
2746000	AFTERBURNER MODULE	337052	020	WORN,STRIPPED,CHAFFED,FRAYED	734
2746000	AFTERBURNER MODULE	337052	804	NO DEFECT-REM FOR SCHED MAINTENANC	734
2746000	AFTERBURNER MODULE	337052	190	CRACKED,CRAZED	912
2746000	AFTERBURNER MODULE	337052	804	NO DEFECT-REM FOR SCHED MAINTENANC	912
2746000	AFTERBURNER MODULE	337052	190	CRACKED,CRAZED	1337
2746000	AFTERBURNER MODULE	337053	190	CRACKED,CRAZED	108
2746000	AFTERBURNER MODULE	337053	020	WORN,STRIPPED,CHAFFED,FRAYED	1346

WUC	NOMENCLATURE	SERIAL #	REASON FOR REMOVAL	DISCRIPTION	TIME SINCE NEW
2746000	AFTERBURNER MODULE	337053	020	WORN,STRIPPED,CHAFFED,FRAYED	1771
2746000	AFTERBURNER MODULE	337053	804	NO DEFECT-REM FOR SCHED MAINTENANC	2233
2746000	AFTERBURNER MODULE	337053	190	CRACKED,CRAZED	3142
2746000	AFTERBURNER MODULE	337054	093	MISSING PARTS	1010
2746000	AFTERBURNER MODULE	337054	190	CRACKED,CRAZED	1266
2746000	AFTERBURNER MODULE	337054	190	CRACKED,CRAZED	2770
2746000	AFTERBURNER MODULE	337055	020	WORN,STRIPPED,CHAFFED,FRAYED	888
2746000	AFTERBURNER MODULE	337057	190	CRACKED,CRAZED	1849
2746000	AFTERBURNER MODULE	337058	804	NO DEFECT-REM FOR SCHED MAINTENANC	2210
2746000	AFTERBURNER MODULE	337059	381	LEAKING-INTERNAL OR EXTERNAL	5
2746000	AFTERBURNER MODULE	337059	190	CRACKED,CRAZED	1183
2746000	AFTERBURNER MODULE	337059	190	CRACKED,CRAZED	9999
2746000	AFTERBURNER MODULE	337060	190	CRACKED,CRAZED	2386
2746000	AFTERBURNER MODULE	337062	070	BROKEN,BURST,CUT,TORN	1103
2746000	AFTERBURNER MODULE	337063	190	CRACKED,CRAZED	975
2746000	AFTERBURNER MODULE	337063		IMPROPER CODE	975
2746000	AFTERBURNER MODULE	337063	020	WORN,STRIPPED,CHAFFED,FRAYED	1131
2746000	AFTERBURNER MODULE	337063	020	WORN,STRIPPED,CHAFFED,FRAYED	1296
2746000	AFTERBURNER MODULE	337063	190	CRACKED,CRAZED	1355
2746000	AFTERBURNER MODULE	337064	190	CRACKED,CRAZED	1389
2746000	AFTERBURNER MODULE	337064	190	CRACKED,CRAZED	9999
2746000	AFTERBURNER MODULE	337065	190	CRACKED,CRAZED	499
2746000	AFTERBURNER MODULE	337065	127	ADJUSTMENT/ALIGNMENT IMPROPER	1021
2746000	AFTERBURNER MODULE	337066	190	CRACKED,CRAZED	1811
2746000	AFTERBURNER MODULE	337066	190	CRACKED,CRAZED	1811
2746000	AFTERBURNER MODULE	337067	020	WORN,STRIPPED,CHAFFED,FRAYED	958
2746000	AFTERBURNER MODULE	337067	190	CRACKED,CRAZED	1765
2746000	AFTERBURNER MODULE	337067	935	SCORED,SCRATCHED,BURNED,GOUGED	1775
2746000	AFTERBURNER MODULE	337068		IMPROPER CODE	1181
2746000	AFTERBURNER MODULE	337070	190	CRACKED,CRAZED	655
2746000	AFTERBURNER MODULE	337070	037	FLUCTUATES,UNSTABLE FREQ RPM	679
2746000	AFTERBURNER MODULE	337071	020	WORN,STRIPPED,CHAFFED,FRAYED	933
2746000	AFTERBURNER MODULE	337071	190	CRACKED,CRAZED	1235
2746000	AFTERBURNER MODULE	337072	190	CRACKED,CRAZED	1211
2746000	AFTERBURNER MODULE	337072	190	CRACKED,CRAZED	2057
2746000	AFTERBURNER MODULE	337073	020	WORN,STRIPPED,CHAFFED,FRAYED	1000
2746000	AFTERBURNER MODULE	337073	190	CRACKED,CRAZED	1324

WUC	NOMENCLATURE	SERIAL #	REASON FOR REMOVAL	DISCRIPTION	TIME SINCE NEW
2746000	AFTERBURNER MODULE	337073	190	CRACKED,CRAZED	1779
2746000	AFTERBURNER MODULE	337074	804	NO DEFECT-REM FOR SCHED MAINTENANC	1282
2746000	AFTERBURNER MODULE	337074	180	CLOGGED,OBSTRUCTED,PLUGGED	1488
2746000	AFTERBURNER MODULE	337075	070	BROKEN,BURST,CUT,TORN	1052
2746000	AFTERBURNER MODULE	337075	190	CRACKED,CRAZED	1867
2746000	AFTERBURNER MODULE	337076	190	CRACKED,CRAZED	1225
2746000	AFTERBURNER MODULE	337077	190	CRACKED,CRAZED	1008
2746000	AFTERBURNER MODULE	337077	020	WORN,STRIPPED,CHAFFED,FRAYED	1176
2746000	AFTERBURNER MODULE	337077	190	CRACKED,CRAZED	1453
2746000	AFTERBURNER MODULE	337079	190	CRACKED,CRAZED	1201
2746000	AFTERBURNER MODULE	337079	020	WORN,STRIPPED,CHAFFED,FRAYED	1689
2746000	AFTERBURNER MODULE	337080	190	CRACKED,CRAZED	607
2746000	AFTERBURNER MODULE	337081	804	NO DEFECT-REM FOR SCHED MAINTENANC	997
2746000	AFTERBURNER MODULE	337082	807	NO DEFECT-REM BY HIGHER AUTHORITY	2677
2746000	AFTERBURNER MODULE	337084		IMPROPER CODE	1001
2746000	AFTERBURNER MODULE	337084	190	CRACKED,CRAZED	1350
2746000	AFTERBURNER MODULE	337084	190	CRACKED,CRAZED	2638
2746000	AFTERBURNER MODULE	337086	190	CRACKED,CRAZED	1521
2746000	AFTERBURNER MODULE	337086	190	CRACKED,CRAZED	2172
2746000	AFTERBURNER MODULE	337087	800	NO DEFECT-REM TO FACILITATE MAINT.	1000
2746000	AFTERBURNER MODULE	337087		IMPROPER CODE	1117
2746000	AFTERBURNER MODULE	337087	190	CRACKED,CRAZED	1206
2746000	AFTERBURNER MODULE	337087	807	NO DEFECT-REM BY HIGHER AUTHORITY	1207
2746000	AFTERBURNER MODULE	337087	190	CRACKED,CRAZED	1556
2746000	AFTERBURNER MODULE	337087	190	CRACKED,CRAZED	1556
2746000	AFTERBURNER MODULE	337089	190	CRACKED,CRAZED	1232
2746000	AFTERBURNER MODULE	337090	037	FLUCTUATES,UNSTABLE FREQ RPM	1599
2746000	AFTERBURNER MODULE	337091	190	CRACKED,CRAZED	2012
2746000	AFTERBURNER MODULE	337091	190	CRACKED,CRAZED	2896
2746000	AFTERBURNER MODULE	337092	804	NO DEFECT-REM FOR SCHED MAINTENANC	992
2746000	AFTERBURNER MODULE	337092	804	NO DEFECT-REM FOR SCHED MAINTENANC	993
2746000	AFTERBURNER MODULE	337093	190	CRACKED,CRAZED	1849
2746000	AFTERBURNER MODULE	337094	799	NO DEFECT	618
2746000	AFTERBURNER MODULE	337094	190	CRACKED,CRAZED	1010
2746000	AFTERBURNER MODULE	337095		IMPROPER CODE	1405
2746000	AFTERBURNER MODULE	337097	804	NO DEFECT-REM FOR SCHED MAINTENANC	350
2746000	AFTERBURNER MODULE	337097	295	FAILS CHECK/TEST	894

WUC	NOMENCLATURE	SERIAL #	REASON FOR REMOVAL	DISCRIPTION	TIME SINCE NEW
2746000	AFTERBURNER MODULE	337097	020	WORN,STRIPPED,CHAFFED,FRAYED	1261
2746000	AFTERBURNER MODULE	337100	190	CRACKED,CRAZED	223
2746000	AFTERBURNER MODULE	337101	020	WORN,STRIPPED,CHAFFED,FRAYED	1611
2746000	AFTERBURNER MODULE	337101	020	WORN,STRIPPED,CHAFFED,FRAYED	1664
2746000	AFTERBURNER MODULE	337101	105	LOOSE OR DAMAGED BOLTS,NUTS,ETC.	1664
2746000	AFTERBURNER MODULE	337103	190	CRACKED,CRAZED	132
2746000	AFTERBURNER MODULE	337103	190	CRACKED,CRAZED	620
2746000	AFTERBURNER MODULE	337103	190	CRACKED,CRAZED	651
2746000	AFTERBURNER MODULE	337103	190	CRACKED,CRAZED	812
2746000	AFTERBURNER MODULE	337103	020	WORN,STRIPPED,CHAFFED,FRAYED	812
2746000	AFTERBURNER MODULE	337104	020	WORN,STRIPPED,CHAFFED,FRAYED	9999
2746000	AFTERBURNER MODULE	337105	020	WORN,STRIPPED,CHAFFED,FRAYED	921
2746000	AFTERBURNER MODULE	337105	093	MISSING PARTS	1744
2746000	AFTERBURNER MODULE	337106	190	CRACKED,CRAZED	1554
2746000	AFTERBURNER MODULE	337107	190	CRACKED,CRAZED	423
2746000	AFTERBURNER MODULE	337107	190	CRACKED,CRAZED	1524
2746000	AFTERBURNER MODULE	337108	020	WORN,STRIPPED,CHAFFED,FRAYED	1716
2746000	AFTERBURNER MODULE	337109	020	WORN,STRIPPED,CHAFFED,FRAYED	2084
2746000	AFTERBURNER MODULE	337109	190	CRACKED,CRAZED	9999
2746000	AFTERBURNER MODULE	337110	190	CRACKED,CRAZED	1056
2746000	AFTERBURNER MODULE	337110	804	NO DEFECT-REM FOR SCHED MAINTENANC	1097
2746000	AFTERBURNER MODULE	337110		IMPROPER CODE	1097
2746000	AFTERBURNER MODULE	337110		IMPROPER CODE	1546
2746000	AFTERBURNER MODULE	337112	020	WORN,STRIPPED,CHAFFED,FRAYED	1001
2746000	AFTERBURNER MODULE	337112	190	CRACKED,CRAZED	1812
2746000	AFTERBURNER MODULE	337112	190	CRACKED,CRAZED	2158
2746000	AFTERBURNER MODULE	337112	190	CRACKED,CRAZED	2158
2746000	AFTERBURNER MODULE	337112	190	CRACKED,CRAZED	2158
2746000	AFTERBURNER MODULE	337112	932	DOES NOT ENGAGE,LOCK CORRECTLY	2435
2746000	AFTERBURNER MODULE	337113	020	WORN,STRIPPED,CHAFFED,FRAYED	893
2746000	AFTERBURNER MODULE	337113	780	BENT,BUCKLED,DENTED,ETC.	1188
2746000	AFTERBURNER MODULE	337113	190	CRACKED,CRAZED	2147
2746000	AFTERBURNER MODULE	337114	804	NO DEFECT-REM FOR SCHED MAINTENANC	1755
2746000	AFTERBURNER MODULE	337114	190	CRACKED,CRAZED	2912
2746000	AFTERBURNER MODULE	337115	190	CRACKED,CRAZED	837
2746000	AFTERBURNER MODULE	337115	070	BROKEN,BURST,CUT,TORN	1477
2746000	AFTERBURNER MODULE	337117	190	CRACKED,CRAZED	1428

WUC	NOMENCLATURE	SERIAL #	REASON FOR REMOVAL	DISCRIPTION	TIME SINCE NEW
2746000	AFTERBURNER MODULE	337117	190	CRACKED,CRAZED	1548
2746000	AFTERBURNER MODULE	337117	190	CRACKED,CRAZED	1764
2746000	AFTERBURNER MODULE	337117	811	NO DEFECT-REM DURING TROUBLESHOOT	2058
2746000	AFTERBURNER MODULE	337118	190	CRACKED,CRAZED	1201
2746000	AFTERBURNER MODULE	337119	190	CRACKED,CRAZED	1156
2746000	AFTERBURNER MODULE	337119	807	NO DEFECT-REM BY HIGHER AUTHORITY	1633
2746000	AFTERBURNER MODULE	337120	190	CRACKED,CRAZED	950
2746000	AFTERBURNER MODULE	337120	105	LOOSE OR DAMAGED BOLTS,NUTS,ETC.	1745
2746000	AFTERBURNER MODULE	337120	190	CRACKED,CRAZED	2101
2746000	AFTERBURNER MODULE	337123	804	NO DEFECT-REM FOR SCHED MAINTENANC	995
2746000	AFTERBURNER MODULE	337123	020	WORN,STRIPPED,CHAFFED,FRAYED	1234
2746000	AFTERBURNER MODULE	337123	135	BINDING STUCK OR JAMMED	1479
2746000	AFTERBURNER MODULE	337123	070	BROKEN,BURST,CUT,TORN	2213
2746000	AFTERBURNER MODULE	337123	105	LOOSE OR DAMAGED BOLTS,NUTS,ETC.	2350
2746000	AFTERBURNER MODULE	337125	190	CRACKED,CRAZED	1131
2746000	AFTERBURNER MODULE	337125	070	BROKEN,BURST,CUT,TORN	1165
2746000	AFTERBURNER MODULE	337125	190	CRACKED,CRAZED	1720
2746000	AFTERBURNER MODULE	337125	804	NO DEFECT-REM FOR SCHED MAINTENANC	5893
2746000	AFTERBURNER MODULE	337126	807	NO DEFECT-REM BY HIGHER AUTHORITY	978
2746000	AFTERBURNER MODULE	337127	190	CRACKED,CRAZED	2564
2746000	AFTERBURNER MODULE	337128	109		1267
2746000	AFTERBURNER MODULE	337129	190	CRACKED,CRAZED	505
2746000	AFTERBURNER MODULE	337129	804	NO DEFECT-REM FOR SCHED MAINTENANC	1552
2746000	AFTERBURNER MODULE	337130	807	NO DEFECT-REM BY HIGHER AUTHORITY	1227
2746000	AFTERBURNER MODULE	337131	020	WORN,STRIPPED,CHAFFED,FRAYED	752
2746000	AFTERBURNER MODULE	337131	020	WORN,STRIPPED,CHAFFED,FRAYED	1611
2746000	AFTERBURNER MODULE	337131	190	CRACKED,CRAZED	7520
2746000	AFTERBURNER MODULE	337132	190	CRACKED,CRAZED	1681
2746000	AFTERBURNER MODULE	337132	020	WORN,STRIPPED,CHAFFED,FRAYED	1998
2746000	AFTERBURNER MODULE	337133	190	CRACKED,CRAZED	1780
2746000	AFTERBURNER MODULE	337136	020	WORN,STRIPPED,CHAFFED,FRAYED	587
2746000	AFTERBURNER MODULE	337136	020	WORN,STRIPPED,CHAFFED,FRAYED	969
2746000	AFTERBURNER MODULE	337136	020	WORN,STRIPPED,CHAFFED,FRAYED	1431
2746000	AFTERBURNER MODULE	337137	190	CRACKED,CRAZED	1448
2746000	AFTERBURNER MODULE	337137		IMPROPER CODE	1906
2746000	AFTERBURNER MODULE	337137	190	CRACKED,CRAZED	2554
2746000	AFTERBURNER MODULE	337138	190	CRACKED,CRAZED	430

WUC	NOMENCLATURE	SERIAL #	REASON FOR REMOVAL	DISCRIPTION	TIME SINCE NEW
2746000	AFTERBURNER MODULE	337138	190	CRACKED,CRAZED	580
2746000	AFTERBURNER MODULE	337139	804	NO DEFECT-REM FOR SCHED MAINTENANC	1526
2746000	AFTERBURNER MODULE	337139	190	CRACKED,CRAZED	1526
2746000	AFTERBURNER MODULE	337139	190	CRACKED,CRAZED	2264
2746000	AFTERBURNER MODULE	337140	804	NO DEFECT-REM FOR SCHED MAINTENANC	478
2746000	AFTERBURNER MODULE	337140	190	CRACKED,CRAZED	1019
2746000	AFTERBURNER MODULE	337140	190	CRACKED,CRAZED	1019
2746000	AFTERBURNER MODULE	337140	093	MISSING PARTS	1612
2746000	AFTERBURNER MODULE	337140	190	CRACKED,CRAZED	1903
2746000	AFTERBURNER MODULE	337141	190	CRACKED,CRAZED	1676
2746000	AFTERBURNER MODULE	337141	935	SCORED,SCRATCHED,BURNED,GOUGED	1850
2746000	AFTERBURNER MODULE	337141	190	CRACKED,CRAZED	2061
2746000	AFTERBURNER MODULE	337142	190	CRACKED,CRAZED	1134
2746000	AFTERBURNER MODULE	337142	190	CRACKED,CRAZED	1176
2746000	AFTERBURNER MODULE	337142	804	NO DEFECT-REM FOR SCHED MAINTENANC	1251
2746000	AFTERBURNER MODULE	337142	190	CRACKED,CRAZED	1472
2746000	AFTERBURNER MODULE	337144	190	CRACKED,CRAZED	1067
2746000	AFTERBURNER MODULE	337144	020	WORN,STRIPPED,CHAFFED,FRAYED	2343
2746000	AFTERBURNER MODULE	337144	190	CRACKED,CRAZED	4614
2746000	AFTERBURNER MODULE	337146		IMPROPER CODE	22
2746000	AFTERBURNER MODULE	337146	020	WORN,STRIPPED,CHAFFED,FRAYED	866
2746000	AFTERBURNER MODULE	337146	020	WORN,STRIPPED,CHAFFED,FRAYED	1634
2746000	AFTERBURNER MODULE	337146	780	BENT,BUCKLED,DENTED,ETC.	1897
2746000	AFTERBURNER MODULE	337146	190	CRACKED,CRAZED	5916
2746000	AFTERBURNER MODULE	337147	190	CRACKED,CRAZED	579
2746000	AFTERBURNER MODULE	337147	190	CRACKED,CRAZED	1619
2746000	AFTERBURNER MODULE	337148	190	CRACKED,CRAZED	761
2746000	AFTERBURNER MODULE	337148	804	NO DEFECT-REM FOR SCHED MAINTENANC	950
2746000	AFTERBURNER MODULE	337148	190	CRACKED,CRAZED	950
2746000	AFTERBURNER MODULE	337148	292	FAILS ACCEPTANCE TEST	1979
2746000	AFTERBURNER MODULE	337149	190	CRACKED,CRAZED	666
2746000	AFTERBURNER MODULE	33715	190	CRACKED,CRAZED	1346
2746000	AFTERBURNER MODULE	337150	070	BROKEN,BURST,CUT,TORN	1607
2746000	AFTERBURNER MODULE	337150	190	CRACKED,CRAZED	1750
2746000	AFTERBURNER MODULE	337151	190	CRACKED,CRAZED	2544

APPENDIX F

SAMPLE LOTUS RESTRUCTURED DATA FORMAT

This is a sample restructured data format that is entered into the LOTUS spreadsheet used to calculate β.

Time Since New -- AEMSM Database							
MODEL	SERNO	HOURS FIRST FAILURE	HOURS SECOND FAILURE	HOURS THIRD FAILURE	HOURS FOURTH FAILURE	HOURS FIFTH FAILURE	TOTAL HOURS
F404GE	337001	1594					2652
F404GE	337002	91	362	633	386	1168	2967
F404GE	337003	1289					1384
F404GE	337004	579	489	105			1691
F404GE	337005	708					1827
F404GE	337006	1117	517				2997
F404GE	337007	1700					1910
F404GE	337009	185					1756
F404GE	337010	989	1558				2547
F404GE	337012	2142	370	328	234		3678
F404GE	337013	705	1145				2831
F404GE	337014						1918
F404GE	337015	69	352	444	528		2455
F404GE	337016	591					1703
F404GE	337017	2	1963				2032
F404GE	337018	1121	484				2655
F404GE	337019	789	2031				3598
F404GE	337020	916	2263				3527
F404GE	337021						1551
F404GE	337022	1533	188				2399
F404GE	337023	1255	1372				3099
F404GE	337024	1694					2946
F404GE	337025	1287					1361
F404GE	337026						760
F404GE	337027						1468
F404GE	337028	1212					1352
F404GE	337030	824	332				1765
F404GE	337031	946	212	1368			2757
F404GE	337032						1318
F404GE	337033	904	612				2186
F404GE	337034						1562
F404GE	337035	1446	260	330			2546
F404GE	337036	2233					2861
F404GE	337037	1126	394				2798
F404GE	337038						280
F404GE	337040	898	101				2049
F404GE	337041						2398
F404GE	337042	1430	500				2369
F404GE	337043	112	771	127			1939
F404GE	337044	640	1361				2139
F404GE	337045	1566	477				2631
F404GE	337046	677	1252				2353
F404GE	337047						1260
F404GE	337048	1576					2310
F404GE	337049	1191					2148
F404GE	337050						1321
F404GE	337051						1198
F404GE	337052	734	178	425			1515

Time Since New – AEMSM Database							
MODEL	SERNO	HOURS FIRST FAILURE	HOURS SECOND FAILURE	HOURS THIRD FAILURE	HOURS FOURTH FAILURE	HOURS FIFTH FAILURE	TOTAL HOURS
F404GE	337053	108	1238	425	1371		3406
F404GE	337054	1266	1504				3264
F404GE	337055	888					2117
F404GE	337056						1840
F404GE	337057	1849					2253
F404GE	337058						2430
F404GE	337059	5	1178				1859
F404GE	337060	2386					2848
F404GE	337062	1103					1400
F404GE	337063	975	156	165			2333
F404GE	337064	1389	610				2246
F404GE	337065	493	522				1393
F404GE	337066	1511					1522
F404GE	337067	958	807				2429
F404GE	337068						2136
F404GE	337069						1387
F404GE	337070	655					717
F404GE	337071	933	302				2433
F404GE	337072	1211	846				2590
F404GE	337073	1000	324	455	410		2486
F404GE	337074	1488					1963
F404GE	337075	1052	635				1731
F404GE	337076	1225					1839
F404GE	337077	1008	168	377			1553
F404GE	337078						523
F404GE	337079	1201	488				1928
F404GE	337080	607					2405
F404GE	337081						2242
F404GE	337082						2031
F404GE	337083						696
F404GE	337084	1350	1288				2943
F404GE	337086	1521	651				3048
F404GE	337087	1206	350				2094
F404GE	337088						2234
F404GE	337089	1232					2387
F404GE	337090	1599					2027
F404GE	337091	2012	884				2938
F404GE	337092						1499
F404GE	337093	1849					1861
F404GE	337094	1010					1286
F404GE	337095						1532
F404GE	337096						968
F404GE	337097	894	367	137			2269
F404GE	337098						1631
F404GE	337099						1306
F404GE	337100	223					2111
F404GE	337101	1611					1734
F404GE	337102						2981

Time Since New – AEMSM Database

MODEL	SERNO	HOURS FIRST FAILURE	HOURS SECOND FAILURE	HOURS THIRD FAILURE	HOURS FOURTH FAILURE	HOURS FIFTH FAILURE	TOTAL HOURS
F404GE	337103	132	488	192			2834
F404GE	337104	1999					2064
F404GE	337105	921					2063
F404GE	337106	1554					1871
F404GE	337107	423	1101				2800
F404GE	337108	1716					2645
F404GE	337109	2084					2724
F404GE	337110	1056					2697
F404GE	337111						2396
F404GE	337112	1001	811	346	277		2819
F404GE	337113	893	295	959			2468
F404GE	337114	1912					2400
F404GE	337115	837	640				1847
F404GE	337116						1640
F404GE	337117	1428	120	200			2058
F404GE	337118	1201					1776
F404GE	337119	1156					1853
F404GE	337120	950	1151				2939
F404GE	337121						1531
F404GE	337122						764
F404GE	337123	1234	245	734			2293
F404GE	337124						1482
F404GE	337125	1131	589				2600
F404GE	337126						1827
F404GE	337127	2564					2759
F404GE	337128	1267					2783
F404GE	337129	505					1595
F404GE	337130						1874
F404GE	337131	752	859				1956
F404GE	337132	1681	317				2367
F404GE	337133	1780					2232
F404GE	337135						1502
F404GE	337136	587	382	462			2928
F404GE	337137	1448	1106				2682
F404GE	337138	430	150	1181			3167
F404GE	337139	1526	738				2271
F404GE	337140	1019	884				2013
F404GE	337141	1676	174	211			2299
F404GE	337142	1134	338				2492
F404GE	337143						2698
F404GE	337144	1067	1276				3186
F404GE	337145						1075
F404GE	337146	866	768	263			2470
F404GE	337147	579	1040				2128
F404GE	337148	761	189	1029			2117
F404GE	337149	666					1859
F404GE	337150	1607	143				2204
F404GE	337151	2544					3034

APPENDIX G

SAMPLE LOTUS SPREADSHEET WITH DATA

This is a sample LOTUS spreadsheet with data used to calculate β equal to 1.278441.

BURNER Module Beta Value

B HAT=	1.278441			
SUM(Ti') ^ B*LnTi' =	853132.6	B HAT EQ:	0.000000	
SUM(Ti' ^ B) =	122903.7			
SUM(Ti) ^ B*LnTi=	2316068.	MTBF=	1164.152	
SUM(Ti ^ B) =	325954.2	Lambda =	0.000858	
SUM(Ln(Ti)) =	339.0328			
r =	54			
SUM ALL (Ti ^ B)=	448857.9			
TOTAL HOURS=	63586			

MODEL	SERNO	TIME FIRST FAILURE	TIME SECOND FAILURE	TIME THIRD FAILURE	TIME FOURTH FAILURE	TIME FIFTH FAILURE	TOTAL HOURS	Ti ^ B	Ln(Ti)	Ti ^ B*LnTi	Ti ^ B	Ln(Ti)	Ti ^ B*LnTi
F404GE	337001	1594					2652	12422.0927	7.374001	91600.53	0	0	0
F404GE	337002	91	362	633	386	1168	2967	319.536376	4.510859	1441.383	1867.06682	5.891644	11000.09
F404GE	337003	1289	95				1384	9468.41277	7.161622	67809.19	337.601546	4.553876	1537.395
F404GE	337004	579	489	105			1691	3403.48325	6.361302	21650.58	2742.36163	6.192362	16981.69
F404GE	337005	708	1119				1827	4401.50810	6.562444	28884.65	7902.26648	7.020190	55475.41
F404GE	337006	1117	517				2997	7884.21452	7.018401	55334.58	2944.69011	6.248042	18398.55
F404GE	337007	1700	21				1910	13487.7892	7.438383	100327.3	49.0207948	3.044522	149.2449
F404GE	337009	185	1571				1756	791.492842	5.220355	4131.874	12193.4071	7.359467	89736.98
F404GE	337010	989	1558				2547	6748.13851	6.896694	46539.84	12064.5609	7.351158	88688.49
F404GE	337012	2142	370	328	234		3678	18124.1925	7.669495	139003.4	1919.97823	5.913503	11353.79
F404GE	337013	705	1145				2831	4377.67865	6.558197	28709.68	8137.75553	7.043159	57315.51
F404GE	337014						1918	0	0	0	0	0	0
F404GE	337015	69	352	444	528		2455	224.316618	4.234106	949.7804	1801.38465	5.863631	10562.65
F404GE	337016	591	565				1703	3493.92154	6.381816	22297.56	3298.63022	6.336825	20902.84
F404GE	337017	2	1963	67			2032	2.42576828	0.693147	1.681414	16210.8874	7.582229	122914.6
F404GE	337018	1121	484				2655	7920.32743	7.021976	55616.35	2706.56463	6.182084	16732.21
F404GE	337019	789	2031				3598	5055.26811	6.670766	33722.51	16932.2418	7.616283	128960.7
F404GE	337020	916	2263				3527	6118.01915	6.820016	41724.99	19443.2469	7.724446	150188.3
F404GE	337021						1551	0	0	0	0	0	0
F404GE	337022	1533	188				2399	11817.6218	7.334981	86682.04	807.938568	5.236441	4230.723
F404GE	337023	1255	1372				3099	9150.30367	7.134890	65286.41	10254.7359	7.224024	74080.46
F404GE	337024	1694					2946	13426.9603	7.434847	99827.40	0	0	0
F404GE	337025	1287					1361	9449.63511	7.160069	67660.04	0	0	0
F404GE	337026						760	0	0	0	0	0	0
F404GE	337027						1468	0	0	0	0	0	0
F404GE	337028	1212					1352	8751.41916	7.100027	62135.31	0	0	0
F404GE	337030	824	332				1765	5343.71253	6.714170	35878.59	1671.58391	5.805134	9703.770
F404GE	337031	946	212	1368			2757	6375.34178	6.852242	43685.38	942.073720	5.356586	5046.299
TOTALS		23338	17009	2945	1148	1168	63586	168557.812	154.3248	1200901.	124227.997	125.5456	893959.9

Ti ^ B	Ln(Ti)	Ti ^ B*LnTi	Ti ^ B	Ln(Ti)	Ti ^ B*LnTi	Ti ^ B	Ln(Ti)	Ti ^ B*LnTi	Ti'	Ti' ^ B	Ln Ti'	Ti' ^ b*LnTi'
0	0	0	0	0	0	0	0	0	1058	7355.780	6.964135	51226.65
3814.445	6.450470	24604.97	2026.754	5.955837	12071.02	8347.318	7.063048	58957.51	327	1639.467	5.789960	9492.451
0	0	0	0	0	0	0	0	0	0	0	0	0
383.6832	4.653960	1785.646	0	0	0	0	0	0	518	2951.973	6.249975	18449.76
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1363	10168.81	7.217443	73392.85
0	0	0	0	0	0	0	0	0	189	813.4367	5.241747	4263.829
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
1645.879	5.793013	9534.605	1068.819	5.455321	5830.754	0	0	0	604	3592.474	6.403574	23004.67
0	0	0	0	0	0	0	0	0	981	6678.432	6.888572	46004.86
0	0	0	0	0	0	0	0	0	1918	15737.31	7.559038	118958.9
2423.957	6.095824	14776.01	3025.024	6.269096	18964.16	0	0	0	1062	7391.352	6.967909	51502.27
0	0	0	0	0	0	0	0	0	547	3164.880	6.304448	19952.82
216.0380	4.204692	908.3736	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1050	7284.748	6.956545	50676.68
0	0	0	0	0	0	0	0	0	778	4965.340	6.656726	33052.91
0	0	0	0	0	0	0	0	0	348	1775.256	5.852202	10389.15
0	0	0	0	0	0	0	0	0	1551	11995.30	7.346655	88125.37
0	0	0	0	0	0	0	0	0	678	4164.494	6.519147	27148.95
0	0	0	0	0	0	0	0	0	472	2621.072	6.156978	16137.89
0	0	0	0	0	0	0	0	0	1252	9122.349	7.132497	65065.13
0	0	0	0	0	0	0	0	0	74	245.3035	4.304065	1055.802
0	0	0	0	0	0	0	0	0	760	4818.949	6.633318	31965.62
0	0	0	0	0	0	0	0	0	1468	11180.84	7.291656	81526.91
0	0	0	0	0	0	0	0	0	140	554.2423	4.941642	2738.867
0	0	0	0	0	0	0	0	0	609	3630.538	6.411818	23278.35
10216.52	7.221105	73774.63	0	0	0	0	0	0	231	1051.332	5.442417	5721.792
18700.53	34.41906	125384.2	6120.598	17.68025	36865.94	8347.318	7.063048	58957.51	17978	122903.7	147.2324	853132.6

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